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Need of and Plan for

RESEARCH ON WATER USE and SOIL MANAGEMENT

towards meeting India's Food Shortages

a report by
Chester E. Evans, Perry R. Stout, Stephen J. Mech,
R. C. Hoon, S. D. Nijhawan, and C.S. Sridharan

International Agricultural Development Service

U. S. Department of Agriculture

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The Government of India has stressed the need for developing a more intensive agriculture and through increased yields, meet the demand for greater food production. Proper use of India's soil and water resources is an essential element in this effort. Education, research, extension and implementation are all necessary to its success. This report deals with the research needed to support the overall effort. It presents the findings of a team of experts who conducted a study early in 1967 and developed recommendations for increasing the effectiveness of the present research program and listing the additional research projects required to provide needed technological information in soil and water management.

The USAID-INDIAN Water Use and Soil Management Research Consultant Team consisted of the following members:

Chester E. Evans, Team Leader and Branch Chief, Soil and Water Conservation Research Division, Agricultural Research Service, U.S. Department of Agriculture, Fort Collins, Colorado;

Perry R. Stout, Professor of Soil Science, University of California, Davis, California;

Stephen J. Mech, Research Irrigation Engineer, Soil and Water Conservation Research Division, Agricultural Research Service, U.S. Department of Agriculture, Prosser, Washington;

R. C. Hoon, Director, Central Water and Power Commission (retired), New Delhi;

S. D. Nijhawan, Agricultural Chemist (retired), Rohtak, Haryana;

C. S. Sridharan, Deputy Agricultural Commissioner (Engineering), Indian Council of Agricultural Research, Government of India, New Delhi.

ACKNOWLEDGMENTS

The USAID-INDIAN Water Use and Soil Management Research Consultant Team are sincerely indebted to the many individuals and groups who made contributions to this report. We find that Water Use and Soil Management Research in India lags alarmingly behind its documented need. About a year ago, Mr. D.A. Williams, Administrator of U.S. Department of Agriculture's Soil Conservation Service, raised the question of this need and in collaboration with officials of the Indian Council of Agricultural Research, Government of India, recommended that this study be made. Many other representatives of USDA/USAID, Washington, D.C., and New Delhi, as well as the several Indian officials and scientists, and particularly Dr. J.S. Kanwar, Deputy Director General, ICAR, New Delhi, are acknowledged for providing technical information and other support for this study.

For significant contributions in providing consultative information, essential contact with individuals and groups, providing basic data, scheduling, developing remainder notes and appendicies 1 through 4, and other related matters, grateful acknowledgment is made to Shri U.S. Madan, Senior Technical Assistant, USAID, New Delhi, who accompanied the Team throughout their tour and participated in their discussions.

We wish to recognize USAID/Washington, D.C., and New Delhi for the financial, secretarial and other support, the India based USAID-SCS/PASA Group, Ford Foundation, Rockefeller Foundation, Indian scientists, and the many other groups located within 14 States in India. These latter include State Departments of Agriculture, Irrigation Departments, Research Institutes and Centers, Field

Stations and Universities. Their unanimously splendid cooperation in preparation of written outlines of their activities relating to soil and water research, special transportation arrangements to reach field sites, staff presentations of current activities and group discussions have been invaluable to the purposes of this study. A special token of appreciation is extended to these groups and personnel whose affiliations are listed in Appendix 2. The USDA's Agricultural Research Service and the University of California, Davis Campus, are thanked for releasing the Team members from their regular assignments enabling them to undertake this study.

NEED OF AND PLAN FOR RESEARCH ON WATER USE AND SOIL MANAGEMENT TOWARD MEETING INDIA'S FOOD SHORTAGES

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SUMMARY AND RECOMMENDATIONS

At the request of ICAR-GOI, a team consisting of 3 U.S. Scientists supplied by USDA under AID sponsorship and 3 Indian Scientists assisted by several active organizations and groups, interviewed over 400 technical people; reviewed related problems, pertinent research activities, needs statements and publications, and facilities at 50 locations in 14 of India's States during the period of January 16 through April 28, 1967. The Team, realizing the magnitude of the assignment, drew heavily on the experiences of many Indian colleagues in research and the excellent and comprehensive reports in the subject area which were prepared for our use.

A greatly accelerated level of research on water use and soil management problems in India in relation to food shortages is of the highest possible urgency. Water management research in India has been assessed and evaluated as India's neglected technology The financial support at the central level for water use and soil management research is grossly inadequate. Research ways and means are charted for shifting management toward positive goals in solving production problems.

Recommendations are made for increasing effectiveness of research involving interdepartmental and interagency relationships. Soil and water conservation problems, research needs, and research program proposals are identified as to water sources, transportation and management of irrigation water to and on farm fields; waterlogging, salinity and alkalinity; soil, crop and climatic influences on irrigated, and rainfed agriculture.

Specific recommendations follow, with the page in the report on which the recommendation is discussed being shown at the right: Recommendations for increasing research effectiveness on immediate food production problems include considerations of:

1. Putting research of an applied or adaptive nature immediately at a level of high concern to the technical people if the goal of more food is to be achieved. 7

2. Rewarding scientists for efforts expended in adaptive research, and providing opportunity for professional advancement by means other than pyramiding through administrative channels. 9

3. Making salaries and related incentives for soil and water research scientists more competitive with those of scientists engaged in nonagricultural endeavors—industrial, construction, or other sectors of India's economy. 10

4. Arranging for more frequent and direct technical leadership and smooth coordination of research in various subject matter areas. These are urgently needed. To accomplish these objectives, the eastablishment of leaders of investigations, either on a national or regional basis, is recommended. 10

5. Improving exchange of technical information which must be achieved with least delay. The following three mechanisms to accomplish early information exchange are recommended:

a. Scheduling a series of technical workshops on water management. 11

b. Development by the ICAR of a systemized plan of routing and distributing interim reports, releases and publications to the soil and water research scientists in India on a timely basis. 13

c. Provisions for technical liaison with scientists in other countries following the "scientist-to-scientist" concept, for the purpose of exchanging current scientific information and publications. 13

6. Identifying Indian soil and water scientists and institutions, which through technical competence and accomplishment in problem solving research have demonstrated capabilities of leadership in applied research programs. Additional resources and support should be channeled and concentrated toward scientific personnel and institutions so identified. 9

7. Identification in the next 2 years of qualified individuals in India, and arranging for expense-free opportunity for them to gain first-hand familiarity at foreign institutions of principles and practices in the irrigation-water use field. 13 14

8. Making contact through the ICAR with foreign universities, with the view of making arrangements to strengthen research and teaching in soil and water science at the graduate level in Indian institutions. 14

9. Consolidation of research projects and stations where possible in order to marshall the available scietific manpower toward the goal of increased food production and concurrently promote an interdisciplinary approach to the solution of agricultural problems. 7

Recommendations for improving interdepartmental and interagency relations and coordination should include clear policy declarations that:

1. In principle, the Ministry providing the leadership for the design and construction aspects of land and water development should also be responsible for the specialized research necessary to implement their pro- 15

grams. It is essential that these research activities be coordinated so that the efforts interlock, but do not overlap.

2. Within the Ministry of Food and Agriculture, water use and soil management research and training activities should be centralized as much as possible. It appears to the Research Consultant Team that this unit is logically the Indian Council of Agricultural Research (ICAR). 16

3. In the States, all agricultural and particularly all water use and soil management research and training activities, except those at institutes, regional centers, and similar units directly and principally sponsored by the center and dealing with problems of regional and national significance in these fields, should be carried out by the agricultural universities within the States. 16

India's intensive crop production programs where adequate supplies of inputs such as seed of high yielding varieties, chemical fertilizers, plant protection materials, mechanization, credit, and trained manpower can be brought to bear show tremendous promise for success in rapidly alleviating food shortages. However, the missing technological links lagging far behind other essential inputs are the transportation and management of irrigation water to and on farm field, general understanding of needs of specified crops, and good soil management practices. To provide essential technological information for the water and soil management component of the "Packages of Practices," the following research projects are recommended for initiation, implementation or strengthening whereby:

1. The best combinations of improved crop, soil, land shaping, fertilization, and tillage practices that might lead toward improved water use efficiency and higher yields of food crops, would be studied within eight river valley projects or tubewell command areas representing important geographic regions of India. 76

2. Adaptive type research programs on water use and soil management problems would be established at designated locations in six river valley projects. 57

3. There would be considerable strengthening of irrigation and water use research at 12 locations where essential land and laboratory facilities are available. 59

4. Pilot research projects would be initiated with high priority within selected command areas which will offer water for purchase on rate schedules based on volume delivery to encourage full water utilization and to discourage overirrigation. 42

5. A pilot research project would thoroughly study full case histories of water transmission and use from single outlet command areas. These would be reported upon in quantitative terms of real water use by cultivators of small holdings in relation to water actually delivered from the command area outlet. 42

6. A pilot research project would make complete studies of cultivators' organizational resources which could provide for equitable methods and rules for water distribution within the single outlet command area. 42

7. A research study on fundamental economics of lining canals, ditches, and cultivator's conveyance channels would be initiated in order to fully evaluate relative savings from minimizing (a) damage to land from seepage, (b) losses of water from seepage, (c) maintenance costs for weed removal, and (d) damages accruing from weed infestations. The cost and benefit estimates discovered from these studies should be compared with capital costs for lining conveyance channels when amortized over periods of 10, 15, 20, and 25 years. 44

8. A pilot research project would be initiated whereby lining materials for ditches for conveying water 44

to cultivator's fields can be tested and evaluated under practical field operating conditions within a variety of typical command areas.

Of equal importance to the research proposals listed above in meeting India's future food needs are steps in research which will lead into longer term programs. Those reeommended for early initiation are:

1. Establishment of coordinated drainage-salinity pilot research projects at one national center and three regional centers to evaluate the application of principles of drainage and the management of salinity and alkalinity in cultivated soils of India. 67

2. In States other than those selected for the centers and where salt problems are acute, appointment of an Indian scientist having a depth of knowledge as to methodology, equipment, and principles and practices for managing salt-affected soils, to be responsible to the interests of cultivators faced with salinity problems even though total areas involved may be relatively limited. 70

3. A research program on basic soil properties in relation to soil and water management practices and production of crops would be initiated at four centers in India. 76

4. Establishment of a central water management research center at the Indian Agricultural Research Institute (IARI) to study water management problems of national significance and to serve as a focal point for the training of people, and for coordination of other programs in India dealing with the management, conservation, and use of water for crop production both on irrigated and rainfed lands. 61

5. Because of the great importance of wells as a source of irrigation water, research would be directed toward problems of well design, construction and maintenance including materials and equipment and evaluation of pumping costs. 27

6. Based on an interdisciplinary and interagency committees' deliberations, an apporpriate budget for research on tanks as catchment and storage structures for water supplies would be established so that various soil groups and climatic belts in India can be advised of the most efficient means of effecting water conservation through construction and maintenance of tanks in small catchment areas. 43

7. A minimum of three research projects would be established to study problems of recharge of underground aquifers to be located at qualified institutions in principal irrigated regions. 43

8. The consultant team studied problems of rainfed lands only in very broad terms. But from evidence observed the team recommends the examination of existing approaches to research on rainfed lands and a substantial strengthening of programs at the soil conservation research, demonstration and training centers throughout India. Emphasis would be placed on small watershed hydrology, sedimentation, and the management of water—its infiltration, storage and drainage from soils and safe disposal of excessive amounts from these rainfed lands having widely varying soil characteristics and slopes. 87

In connection with other essential activities, including the appointment of study groups or committees, it is suggested that:

1. USAID explore with ICAR its need for experienced foreign specialists to assist with such additional planning activities that may be desirable and needed.

2. An Indian study group be formed with interdisciplinary and interagency representation to study the benefits which might accrue from research studies of tanks in relation to improvements which could contribute to India's economic development and to make recommendations for practical ways in which to get an effective research program started. 43

3. The ICAR actively consider possibilities for chemical control of aquatic weeds within the realization, however, that India's water distribution systems pose special problems involving use of water for human and animal consumption. 44

4. A technical committee of Indian seientists be designated to make an assessment of existing findings for rainfed lands, publish the results, and make detailed suggestions as to the direction and orientation of needed soil and water conservation research expansion for rainfed lands in India. 89

5. If not already surveyed, existing experimental fields and those planned for research in India should be surveyed and characterized as to the kinds of soil represented by the test areas. 71

INTRODUCTION

At the request of the Indian Council of Agricultural Research (ICAR), Government of India (GOI), and in accordance with recommendations and agreements by Dr. B.P. Pal, Director General of ICAR, Mr. D.A. Williams, Administrator of U.S. Department of Agriculture's Soil Conservation Service, made arrangements with the United States Agency for International Development (USAID) to select three Water Use and Soil Management Research Consultants. They were Dr. Chester E. Evans and Mr. Stephen J. Mech of the USDA Agricultural Research Service, and Dr. Perry R. Stout of the University of California, Davis. Their study was made in India during the period of January 16—April 28, 1967.

The 'Operational Work Plan' jointly signed on September 23, 1966 by Oliver A. Bauman of USAID, New Delhi, and Mahavir Prasad, Irrigation Advisor, Department of Agriculture, GOI, stated:

"These men will assist in developing, under ICAR leadership, a comprehensive water management research program for the Fourth Plan Period. The plan will be considered by the GOI in undertaking a comprehensive water management research program utilizing facilities and resources available in the Country."

Upon arrival of the team in India, Shri U.S. Madan, Senior Technical Assistant, USAID, New Delhi, was assigned to assist the team and three Indian scientists were designated as counterparts consisting of Dr. R.C. Hoon, Director, Central Water and Power Commission (Retired), New Delhi; Dr. S.D. Nijhawan, Agricultural Chemist, Punjab (Retired), Rohtak, Harayana; and Shri C.S. Sridharan, Deputy Agricultural Commissioner (Engineering), ICAR, New Delhi.

TERMS OF REFERENCE

Discussion sessions were held on January 21 and 27, 1967, in New Delhi to more closely define the areas of coverage desired from the Team. Participating were J.S. Kanwar and N. Patnaik of ICAR; E. Hatt* of Ford Foundation; G. Baird* of Rockefeller Foundation; J.T. Phelan and J.R. Coover of USAID-SCS/PASA; and S.D. Nijhawan, R.C. Hoon, C.S. Sridharan, U.S. Madan*, C.E. Evans, P.R. Stout, and S.J. Mech. The following guidelines evolved from these discussions :

Although the GOI seeks advice in all aspects of the soil and water management research field, the specific areas on which recommendations are requested include financing, organization of programs by locations, short-term (2-3 years) and long-term research, and research on intensive as well as extensive types of agriculture in the soil and water management problem areas.

Toward this end, the following priorities, in decending order were identified:

1. Long-term research need for basic information in soil-water-plant relationships, salinity-alkalinity, drainage and other related problems.

2. Short-term applied research to develop criteria and guides for systems and methods of efficient irrigation, field layout, cultural methods and related practices, especially with reference to high yielding varieties, intensive cropping and small fragmented holdings.

3. Recommendations for computation of provisional consumptive use estimates based on available meteorological data for major irrigated crops as well as suitable cropping programs for agro-climatic zones to be suitably delineated by the team.

4. Studies of the problems associated with the system of irrigation and supply of water in the canals, distributories and farm channels and its complete management.

* Present in only one of the briefing sessions.

5. Research needs in minor irrigation, engineering, agronomic and soil problems.

METHODS OF EVALUATION

The Team toured 14 of India's 17 States. Only Assam, Kerala, and Jammu & Kashmir were not visited (see Appendix 1 for itinerary and map of tour routes). As listed in Appendix 2, some 400 technical people at 50 locations were contacted in the 14 States and Delhi. Appendix 3 gives the chronological listing of soil and water research, demonstration and other projects visited (also a map showing the location of these projects in India). Visits were made to 11 Centre-sponsored research installations, 7 State Universities, 27 State Departments of Agriculture and Departments of Irrigation, and 4 Autonomous Institutions, all of which are engaged in some phase of research on water, soil, or associated resource problems. In addition, approximately 13 demonstrational or developmental projects were visited. Appendix 4 lists and shows by map the soil and water research activities by location and category in India. Farmers and farm managers were also met and problems discussed with them.

The assignment was approached by observing water use and land utilization problems, interviewing people, reviewing research progress and plans with technical and nontechnical people and receiving and reviewing publications, reports, and plans.

WATER USE AND SOIL MANAGEMENT RESEARCH ON IRRIGATED AND RAINFED LANDS — INDIA'S NEGLECTED TECHNOLOGY

Water supply systems for irrigated agriculture in India range from simple hand pumped shallow wells to bold, huge-scale engineering works which are modern triumphs in commodity storage and transportation. As an example of the latter, an acre foot of water costing Rs.40 ($ 5.38) delivered via canal to a growing crop in a cultivator's field, means that water had to be harvested from a watershed, stored until needed and then delivered to site of use for 3 paisa (0.4 cents) per ton. Even so, the price of water may represent a substantial fraction of the total farm production cost.

There are large public responsibilities and expenditures in the management of water from rainfed lands as well as development of supplies of water for irrigation purposes. The latter demands efficient storage, judicious distribution, and delivery to the farmer in the right amount at the right place and at the right time. Losses in quantity and quality during transit from source to farm must be avoided. The farmer's need for irrigation water depends on a multiplicity of factors, among the most important of which are crops being produced, the consumptive use of water for each crop in relation to its stage of plant development, and the amount of this need that is met by variable rainfall. And, different crops vary as to their needs and the need fluctuates as each crop develops and reaches maturation. Some water is unavoidably lost through seepage from farm ditches, percolation of water beyond the rooting depth in soils, and runoff losses at the bottom of the field. Land levelling and shaping are critical for proper distribution of water into the root zone or over a flooded area. Soils differ widely as to water intake, storage, and retention characteristics and these determine the irrigation method and practice best suited for the crops to be grown on any one particular piece of land. Soil fertility and cultural practices are factors to be considered. In total, all these conditions must be evaluated before the irrigation water requirements can be determined for any particular farmer for any given period of time during the year. And, there are an estimated 70 to 80 million acres of irrigated land in India.

Irrigation water requirements for any command area must be based on an integration of each farmer's needs as the growing season progresses. Provisions must be made to vary deliveries in accordance with the rainfall pattern each year. A loss factor for conveying the water within the command area must be added. Agriculturists must supply these water requirement figures to the engineer in order that he can design the distribution system to supply the irrigation water requirements needed by the cultivator throughout the year.

Many irrigation projects have been planned and constructed upon the philosophy of providing a small amount of irrigation water to a large area, thereby benefiting the greatest number of people. Only recently have policies been adopted to promote intensive use of

irrigation water for maximizing the amount of food produced with a given quantity of water.

But too little information on real water need on farm fields is available in India.

Thus groups responsible for the development of irrigation water supplies have proceeded with construction of major, medium, and minor irrigation projects in spite of the paucity of information on irrigation water requirements for crop production as applied to large command areas or to farmers' individual fields. Usually this has resulted in gross inefficiencies of use of available irrigation water supplies, irreplaceable losses of productivity, and serious delays in closing the food shortage gap in India.

This is India's neglected technology.

Despite the strong recommendations for increased water use and soil management research that have been made in documents, the current effort being directed toward water management problems in India remains alarmingly low. (See pp. 46-53, Ref. 5, Ref. 12 ; pp. 40-58, Ref. 17 ; p. 23, Ref. 1.)

A greatly accelerated water use and soil management research program must be launched which is geared to providing information on irrigation water requirements for food crops under each major soil-climatic-cropping pattern complex in India.

Resources directed toward soil and water conservation research in India are pitifully low and inadequate. Although direct comparisons are not possible, funds from the Center proposed for research on utilization of these resources in the Fourth Five-Year Plan in India are less than one-nineteenth of appropriated federal money in the USA for similar research when the ratio is based on the expenditure per cultivated acre per year in the two countries. This comparison is based on an area of about 457,000,000 acres of land under cultivation or in permanent crops in the U. S. and a federal expenditure of $34.6 million (Rs. 25.95 crores) for research on 'Resource Conservation and Use' during the period July 1, 1964 through June 30, 1965 in the United States. (Ref. 2). In contrast, India

with over 400,000,000 acres in comparable crops, some of which produce two crops per year, proposed to spend Rs. 1.325 crores per year (See Appendix 5) during current Five-Year Plan. These estimates do not include requests for support of Institutes, some of which, like the Indian Agricultural Research Institute and the Central Arid Zone Research Institute, are directing varying portions of their resources toward soil and water conservation research. India is proposing to spend hardly 3 paisa per acre on soil and water management research, as compared with 57 paisa per acre in U.S.A. If we consider the expenditure which has been made in the past on this research program, the gap becomes still wider. The grossly inadequate level of support for research on water use and soil management problems appears to the Team to indeed be a dominant factor in not providing the needed technology and its application to the land and water resources needed to help meet India's food shortages.

GENERAL RECOMMENDATIONS FOR INCREASING RESEARCH EFFECTIVENESS

RECOGNITION AND DEFINITION OF IMMEDIATE GOALS IN WATER USE AND SOIL MANAGEMENT RESEARCH

The available scientific talent in India must devote a major effort to those problems whose solutions will have an immediate effectiveness in alleviating food shortages.

While understanding the ICAR viewpoint that long range as well as short term research problems are in dire need of additional financial support, it appears that available resources do not permit top priority on both. In the land and water management area, the payoff will come from problem solving research which can give answers on how to correct elements of management that are now adversely affecting the production of food and that may be improved substantially in the next few years. This does not mean that long range or the more fundamental types of research in the soil and water utilization fields should be neglected. It does mean that a higher proportion of the available scientific talent, facilities, and funds (those available under existing programs as well as those yet to be allocated) should be directed toward research into why and how land and water management practices can be improved and fitted more effectively into the farming systems of India's several climate-soil-crop complexes to maximize food production.

Consolidation of research products and stations is necessary in order to marshall the available scientific manpower toward this goal. In most instances, an interdisciplinary approach is required for greatest progress. This can be attained more effectively at the larger research centers.

As cases in point, from visits to the ICAR sponsored Indian Agricultural Research Institute (IARI), New Delhi ; the Central Arid Zone Research Institute (CAZRI), Jodhpur (Rajasthan) ; the Central Sugarcane Research Institute (CSRI), Coimbatore (Madras)* ; the Central Rice Research Institute (CRRI), Cuttack (Orissa) ; and the substation for Saline Areas at Canning Town (West Bengal), it was found that the IARI and CAZRI programs included research on water use and soil management problems, but the levels of support are grossly inadequate, particularly in the areas of junior professional staff, equipment and instrumentation. At CRRI and its substation, and at CSRI, virtually no research was being done on irrigation, water use, and soil management problems, though these Institutes are national centers for rice and sugarcane research. The Team strongly recommends that the research programs at CRRI and CSRI be broadened to include a strong irrigation, water use, and soil management activity in association with existing programs at the Institutes. This would then permit an interdisciplinary approach to the solution of the several problems associated with the production of rice and sugarcane. Although not visited by the Team, we understand that other Institutes under ICAR including Central Jute Research, Calcutta, (West Bengal) ; Central Potato Research, Simla (Himachal Pradesh) ; Central Tobacco Research Institute, Rajamundry (Andhra Pradesh) ; Indian Grassland and Fodder Research Institute, Jhansi (Uttar Pradesh) and Central Tuber Crop Research Institute, Trivandrum (Kerala) are crop oriented and, as such, the research programs do not now include irrigation, water use, and soil management research. Here again, the Team strongly recommends an interdisciplinary approach. To get early solutions to problems associated with the production of any given crop, the total program of research must include studies of those resource problems directly related to the production of that crop.

Closely associated with the need for focus on immediate goals of India in water use and soil management research is a principle of research administration that should not and cannot be overlooked.

* Currently under the Ministry of Food, Agriculture, Community Development and Cooperation.

This is an early identification of individuals who have demonstrated scientific competence and capacity for carrying on a vibrant research program leading to the solution of significant problems in agriculture. To a lesser, but none the less important, degree is the capability of an institution whether it be an Institute, Agricultural University or College, or other autonomous body, to provide an environment, facilities, and other intangibles conducive to success in research. These individuals and institutions should be identified and if the problem to be studied is significantly represented in the area where the institution is located, financial resources should be directed toward the support of these people and places.

INCENTIVES FOR THE SOIL & WATER RESEARCH SCIENTIST

The "Post" system, now generally operative in India, is not conducive to keeping well-trained and experienced individuals in soil and water research on a career basis. Often, promising individuals are attracted away to other activities because of higher salaries available either in nonresearch positions or research positions in fields not closely allied with their training, experience, and interest. Financial and professional incentives for research scientists need major revision. Guides for the advancement of scientists should be adjusted in the direction of reward for documented solution of applied problems as well as publication of scientific papers in national and international journals. Unfortunately, the present criteria for professional advancement are not effective in meeting India's immediate food crisis.

The scientist who directs his efforts toward the solution of today's soil and water management problems and whose accomplishments can be documented, should be specially rewarded, and permitted to continue in his assignment at substantial and progressive increases in salary and related fringe benefits.

It is recommended that a promotion plan for research scientists similar to that of the U.S.D.A. Agricultural Research Service (ARS) be adopted (Ref. 7). The essential features of the plan include two routes of advancement available to career scientists, namely

(1) promotion through the Evaluation Plan covering evaluation and classification of personnel engaged in the conduct and/or leadership of research and (2) the promotion of scientists engaged in management or administration of research. The qualification requirements for advancement differ for each route and a separate set of guides are used for each. A scientist can cross over from one route to the other as he progresses in his career but the usual line of advancement is either as a "research scientist" or as a "research administrator". (The research administrator as used here must have had training and experience in research). Promotion from one level to the next for either category is based on documented evidence of accomplishment. Thus, a research scientist need not move into the "research administrator" category to be promoted, provided he can document his accomplishments. Neither, does the research scientist have to move to another location in order to be promoted to a higher grade.

It is clearly evident to the Team that soil & water research scientists in India receive drastically lower salaries than scientists in non-agricultural endeavors—industrial, construction, or other sectors. Agricultural research does not command salaries and other incentives that are required for attracting and holding top people. Future food production potentials of the country will undoubtedly be closely allied with an understanding and the application of technological advancements in agriculture. Therefore, well-trained and experienced people are and will be imperative for this job. Salary and other incentives, together with a much accelerated program of acquainting promising young people with the opportunities and challenges in agricultural research, must be strengthened immeasurably if India's future food needs are to be met.

TECHNICAL DIRECTION AND INFORMATION EXCHANGE

Research Investigations Leaders

Establishment of leaders of investigations is recommended (national or regional responsibility for the technical excellence of program) in such areas as consumptive use of water by crops; irrigation methods and practices ; drainage ; salinity and alkali ;

management of water on uplands; water supply, water conveyance and seepage control; etc. Research leaders and institutions in the various subject matter fields should be identified and supported.

The Indian scientist who through research accomplishments has demonstrated technical competence in the subject matter area involved as well as leadership ability, should be given responsibility for the technical excellence of this research either in a given region or throughout India. He should also be responsible for developing recommendations and publications of a national (or regional) character embracing all of the research results on the subject. Those so designated as Research Investigations Leaders should be appropriately rewarded in terms of salary increases as well as funds in amounts sufficient to finance the additional costs incurred.

To hasten the implementation of this program and realization of its possible benefits, it may be desirable for GOI to request the assistance of a foreign scientist to work as a colleague of the Indian Investigations Leader in specific selected areas of the soil and water research field. If so designated, the scientist should spend a minimum period of one year in India. The two scientists should be at the same location (in most cases, the present headquarters of the Indian scientists) and each should undertake an active research program either through junior scientists, graduate students or others as well as give technical guidance to the research carried on elsewhere.

Exchange of Technical Information

Interchange of ideas, plans, approaches, techniques, and procedures, in most instances, needs substantial strengthening and emphasis in India.

The four Zonal Conferences on Soil Science held earlier this year are significant steps in the right direction. The highest commendation for insight should be accorded those responsible for these sessions. Similar workshops are urgently needed on problems of water management and use. However, the subject matter for early discussions should be oriented toward upgrading the understanding

of modern principles and techniques relating to soil and water management.

To accomplish the goals mentioned above, a series of technical workshops, each of about 2 to 3 weeks' duration should be scheduled and held as early as possible. Methodology and technique along with procedures to be used in experiments should be highlighted at these workshops. Prior to the workshop, pertinent technical releases such as Chapter 1, "Soil-Plant-Water Relationships", Section 15 IRRIGATION, (March 1964) and technical Release number 21 "Irrigation Water Requirements", Engineering Div. Soil Conservation Service, U.S. Department of Agriculture, April 29, 1964, should be made available to participants for detailed study. An experienced technical authority in the subject matter field, from the U.S.A. or elsewhere, should be invited to give seminars and lead discussions at these workshops.

More effective and timely exchange of significant reports and publications needs to be achieved among technical and scientific personnel in India. In numerous instances, research workers in one State were not aware of releases of information in an adjacent State, Institute, or other organizational unit, even though the research results available would have had a direct and significant bearing in planning and executing their own research. The investigations leader, mentioned above, can be a key individual in facilitating communications among research workers directing their efforts toward the same end. Firstly, he can assume responsibility for disseminating selected reports and publications, both from within India and from other countries, to his colleagues working in the particular technical area involved. Secondly, he should be responsible for assembling, and summarizing existing experimental findings within his technical area and making broad regional or national interpretations of the results in publications for use by other scientifically and technically oriented groups whose primary function is application of research results.

The Indian Council of Agricultural Research should also develop a systematized plan of routing and distributing interim reports,

releases, and publications to the soil and water research scientists in India on a timely basis. If not already available, a national roster of workers by subject matter areas should be developed and this roster used along with suggestions enumerated above as a basis for strengthening the exchange of technical information.

Another mechanism for strengthening information exchange is the "scientist" to "scientist" concept, such as is operative in some P.L. 480 research projects. If successfully implemented, Indian scientists would develop a technical liaison with scientist(s) in other countries to exchange current scientific information and publications. The scientific interests of the two would need to be closely allied and the exchange would have to be mutually advantageous for the plan to be of greatest success.

TRAINING NEEDS OF INDIA'S SCIENTISTS TO MEET FUTURE GOALS IN WATER USE

The Team at every opportunity attempted to assess whether recommendations for needed research activities could be met with scientifically trained people available or in prospect. We must now conclude that at the current rate of training activity in the subject area of land and water management, the basic requirements will not be met unless action of the highest priority is put forth. All of us recognize that research depends on ideas and ingenuity of people. In many cases, the success or failure of a research project hinges on whether the scientist has had basic technical training and whether he has had an opportunity for retraining at periodic intervals. For effective progress in research, we must have people who are well trained in concepts of basic science and possess a depth of knowledge of modern and advanced technology. They must be supported by availability of current information which will permit them to keep abreast of changes in technology.

We have pointed out earlier that water use is India's neglected area of technology. One reflection of this is in the small number of people trained and experienced in water science as related to agricultural use. More scientifically trained people are needed in the engineering phases of irrigation, drainage, and soil and water conservation

as well as in application of principles to soil-water-plant relationships.

We have seen exemplary instances of water use and conservation curricula established and underway at IARI (Delhi), IIT (Kharagpur, West Bengal), and Punjab Agricultural University, Ludhiana, and beginnings of such curricula at U.P. Agricultural University, (Pantnagar), Jawaharlal Nehru Agricultural University (Jabalpur, Madhya Pradesh). At a few other places, the need for instruction is recognized. But all of these efforts will fall far short of meeting the need for well-trained people, in the time span required. We therefore, recommend most strongly that people from India having some training and interest in the field of water science be detailed at the earliest possible date to foreign universities having successful programs of research and teaching in soil and water science. We hasten to add that academic training opportunities in India should be strengthened and broadened as rapidly as circumstances and opportunities present themsevles.

Specifically, we recommend : (a) that in the next two years qualified individuals be identified and given an expense free opportunity to become familiar with principles and practices in the irrigation water use field at foreign institutions, and (b) that contacts with foreign universities be made with the view of making arrangements to strengthen research and teaching in soil and water science at the graduate level in Indian institutions.

INTERDEPARTMENTAL & INTERAGENCY CONSIDERATIONS

Varying degrees of segmentation of water use and land utilization research now exist among and within the Ministries of Food & Agriculture and Irrigation & Power at the Center as well as among Departments, Universities, Agriculture Colleges and other autonomous bodies in the States.

As to the Ministries, there should be a clear policy that, in principle, the Ministry providing the leadership for the design and construction aspects should also be responsible for the specialized research necessary to implement their programs. It is essential that these research activities be coordinated so that the efforts interlock but do not overlap.

The two Ministries involved in the planning and construction of irrigation and drainage projects and in the utilization of the water supply and the installation of the on-farm measures to make the project works useable, must coordinate their efforts to assure that all aspects of project investigation and implementation are integrated. Soil surveys and classification are equally as important as hydrologic investigations and analyses for matching the soil resources with the water supply. The drainage potential and reclamation measures needed in different areas must serve as the basis for the location and design of major drainage works. The Government of India has recognized this need and has established a Water Utilization Cell within the Ministry of Food & Agriculture to promote coordinated efforts in water research, development and utilization. It is essential that efforts of this nature be continued and strengthened.

Within the Ministry of Food & Agriculture, water use and soil

management research and training activities should be centralized as much as possible. It appears to the research consultant Team that this unit is logically the Indian Council of Agricultural Research (ICAR). At the present time, the water use and land utilization research relating to Minor Irrigation Projects is separated administratively from other agriculture research endeavors. The Research Consultant Team makes the strongest possible recommendation that these research activities be transferred to the ICAR. We hold this view on the premise that water use and associated soil management as well as the agriculturally related complex of research problems and their solutions can be no different whether the project be minor, medium, or major in scope. Other phases of these projects such as planning, construction, and development should be the responsibility of the Minor Irrigation Unit directly under the Department of Agriculture of the Ministry of Food & Agriculture. The Team notes steps in these directions in the recent alignment of Soil Conservation Research, Demonstration and Training Centres under the ICAR.

To avoid duplication of effort and at the same time insure against an important facet or area of agricultural research being overlooked or emphasized too little, all Center or Center-sponsored research programs should be guided by an advisory scientific panel comprised of experts in the particular subject selected from both the Center and the involved States. The panel should meet at least once a year or as frequently as required to perform this function.

In the States, all agricultural, and particularly all water use and soil management research and training activities, except those of Institutes, Regional Centers, and similar units directly and principally sponsored by the Center and dealing with problems of regional or national significance in these fields, should be carried out by the Agricultural Universities in the States. Agricultural research in some of the States has been transferred to the Universities. In the States where agricultural research still remains with the Department of Agriculture or the Department of Irrigation, transfer to the University is recommended. In States and the Union Territories such as Madras, Maharashtra, Gujarat, Jammu & Kashmir, Assam, Kerala and Himachal Pradesh, where Agricultural Universities have not been

established, the leading Agricultural College of the State should have the responsibility for all types of agricultural research. Universities and Agricultural Colleges should direct their major effort toward agricultural research problems indigenous to or of significance in that State.

WATER USE AND SOIL MANAGEMENT PROBLEMS, RESEARCH NEEDS, AND RECOMMENDATIONS

IRRIGATION WATER—ITS SOURCE & TRANSPORTATION TO THE FARM

Problems of Water Delivery Between System Outlets and Cultivator Fields

Depending upon individual circumstances, a cultivator may obtain irrigation water from his own private well or tank, from a privately owned neighbouring well, a village-owned community tank; or from a State-owned canal, tubewell or tank. In some cases, private wells may supplement outside primary sources. Distribution of water to the cultivated field is nearly always by open channel, although water from State-owned tubewell in West Bengal is delivered through buried impervious conduits to risers, each of which serves 20 acres. Similarly, a few private tubewell owners in Punjab have followed an analagous practice. Delivery outlets of State-owned system usually serve command areas varying from 100 to 300 or more acres, whether from canal or tubewell. Some tubewells command about 500 acres but can irrigate only a fraction of the reachable area. Transfer of water from outlet to the actual fields is left to the cultivators' own devices.

Water charges—the case for distribution on a volume basis—Charges for water from privately owned wells are negotiated directly between supplier and consumer. Water charges from canal systems are based on flat rates per area per crop. The rates vary with circumstances, but examples are Rs. 8 to Rs. 40 for wheat up to Rs. 300 per acre for sugarcane. Temporarily, West Bengal is supplying water free of charge for wheat as a means of encouraging cultivators to

try wheat as a rabi (winter) crop. However, in the main—more particularly as applied to the larger canal systems—it appears that methods of levying water charges are more akin to revenue collection than a charge for the product delivered. For example, in most instances the moment a cultivator takes water for a crop he is fully obligated to pay the entire flat rate charge for that crop. The fee is collected by the Panchayat (Local Government) and deposited to the State's account. However, since the State assumes no obligation to provide the specific cultivator with a sufficient number of irrigations needed to see his crop through, his obligatory fee assumes the element of an irrevocable tax rather than a purchase. These schedules for payment may explain much of a cultivator's reluctance to accept water from the State's outlet if there is any alternative open to him—especially if his holding is located in an unfavourable position with respect to the delivery outlet where his disadvantages may be compounded further by longer channels, seepage losses, and weed obstructions.

Cultivators near the outlet are not faced with these inequities to the same degree but, in this instance, flat rate charges for water encourage overirrigation at points within the command area where water is more easily obtainable. These are kinds of problems within the cultivators' command area which may serve in explaining some of the paradoxical situations which exist with respect to underutilization of irrigation water from some canals and tubewells. Apparently, a sense of mistrust has been generated among cultivators whose holdings are less favourably located from delivery outlets, to such an extent that some of the newer canal systems have not acquired a sufficient number of water consumers to use the water made available. The Report of the Working Group for the Formulation of the Fourth Five-Year Plan Proposals on Minor Irrigation (pp. 106-107, p. 122 para 11) (Ref. 16) has raised the question of "causes pertaining to water management responsible for under or delayed utilization." Their analyses seem well taken. Although methods of levying charges are not mentioned, the working group has pin-pointed other features which may be contributing to cultivator reluctance to make full use of irrigation water. From the point

of view of land and water management factors, they call attention to "excessive wastage of water in field channels", and inadequacies in technical knowledge and guidance which would help the cultivators in laying out field channels, selecting cropping patterns, and initiating practices needed to take full advantage of irrigation agriculture.

A further observation which may bear upon the cultivator's confidence in water to be supplied from Government sources has to do with the "water master" who may or may not understand his full responsibilities to adjust outlet flows accurately. Under the cultivator's present system of "*waribundi*" (predetermined rotational use of the water stream for a fixed time), the *quantity* of water delivered during a cultivator's turn depends first upon the *rate* of delivery at the outlet. Whether justified or not, there is a popular assumption throughout India that some water masters, through carelessness or intent, do not perform their functions as intended so that some cultivators may get too much water and others too little. Similarly, in the case of tubewell operators, "breakdowns", "power failures", and repair and maintenance delays are thought to be due as much to "operator failure" as to real mechanical trouble. Unfortunately, such discrepancies may cause the cultivator to lose his turn in the waribundi. As to volumes delivered while pumping, cultivators keep a sharp eye on the watt meter registering electrical power consumed by the pump motor since the watt meter gives a secondary indication of total volume of water pumped. In recognition perhaps of these latter kinds of potential for inequities in water distribution, the Report of the Working Group for the Formulation of Fourth Five-Year Plan Proposals on Soil & Water Management (p. 66, item vi) (Ref. 17) has suggested that "the institution of reliable water masters should be introduced" as one of the prerequisites for successful sale of water on a quantitative basis.

There are important, fundamental agronomic reasons for delivering known amounts of water to fields—regardless of methods of collecting payments. Recognizing the current stress on increasing food production, it is admitted in all quarters that every avenue for increasing crop-producing capability must be exploited. Intensive, efficient cropping during rabi (the dry winter season) with expansion

into the many million acres idle during that season is the most hopeful way of meeting the urgency at an early date. Obviously, since water is the limiting factor in rabi cropping, overuse of available water must be avoided so that more acres can be irrigated. Considerable amounts of water can be saved by irrigating fields in accordance with crop needs rather than according to more or less arbitrary schedules as is now the case.

Cultivators who take water will have to be taught—if indeed they do not know this already—that lesser quantities of water are needed for plants in seedling stages than when they are growing rapidly towards maturity. That is, the efficient cultivator will have to apply the *volume* of water needed to replace the *volume* of water evaporated and transpired from his field during the *growth* of his crop. Since much less water is needed in the early stages of plant growth than later in the season, deliveries will have to be timed accordingly. These are reasons why responsible agencies engaged in providing irrigation water will have to deliver water to cultivators on a modified demand and volume basis—all arguments to the contrary notwithstanding.

Some agricultural scientists, experienced in Indian agriculture, feel strongly that volume-based delivery to individual cultivators at whatever time the cultivator calls for delivery, would be an overwhelming task and perhaps impossible to achieve because of the great number of irrigators and their small, scattered holdings. But, while appreciating the ultimate difficulties involved, the urgency for moving promptly in this direction becomes no less.

In Maharashtra there has already been an investigation of *volume sale* of irrigation water which has produced good results. Specifically, this experiment, introduced in 1958 with 13 consumers, showed a saving of 29% in water used when deliveries were changed from an area to a volume basis. (p- 65, Ref. 17). The trial involved only large holdings with units ranging between 300 and 4,250 acres. The question of transferring the experience to small holdings remains open.

However, there have been frequent private suggestions made also,

by Indian agricultural scientists, that cultivators within an outlet command area might well be able to solve problems of water distribution on a quantitative basis if they were but given guidance by a trained irrigationist. A pilot research project directed toward accomplishing this with full cultivator participation would be well worth the effort and should be given very high priority. Consideration must be given to the water delivery limitations peculiar to the particular canal system and the need for closures for canal maintenance.

As a start toward such a project some well-documented facts can be assembled through direct test and measurements within typical command areas. The studies should be done in such a way that real, indisputable data can be made available on the fate of water enroute between the outlet and cultivator's individual holdings. The basic equipment needed will be a set of reliable integrating water meters (purchased or improvised) which can accurately account for all of the water being distributed from the command outlet to cultivated fields during the time period of the experiments. If such studies are made, the results will be valuable and no doubt very convincing. The data can be used as a base for initiating positive measures in future distribution system designs as well as for devising procedures whereby cultivators of small holdings can begin to carry out informed water management practices.

A thorough examination of field-to-field irrigation must not be overlooked because here is a special instance where the uppermost field can be thoroughly overirrigated while the bottom area may suffer.

Eventually the time will come when irrigation water will have to be metered out and distributed on a volume basis. The sheer weight of need for agricultural efficiency will force this step. Water meters of reasonably good precision will have to be designed for a number of different rates of flows so that both the managers of water distribution and the users of water will be in position to handle volumes of water properly. In these respects, technical branches of Weights & Measures, Irrigation and Power, Minor Irrigation, and Agricultural Engineering establishments should be made aware of

the need at the earliest date. They will need time to review the full implications of distributing water on a volume basis and to devise ways of adjusting their future responsibilities accordingly. Research engineers should be given the charge to invent and develop the adequate, integrating water meters which will be needed.

Need for policy on pricing water as a commodity—Cultivators, once beyond the harsh subsistence level, should be motivated by incentives to make a profit. With oncoming needs for heavier investments in fertilizers, pesticides and mechanical aids, the cultivator will gravitate increasingly toward business methods and will view his water supply as a legitimate part of production costs. When water is sold on an area basis, it is only natural for the cultivator to take as much as he can, first because he reduces the gamble with drought, and second, less care is needed in land levelling and attention to crop than when smaller amounts of water are used. These tendencies to overirrigate are in conflict with the public interest in conserving water supplies, especially where circumstances dictate that maximal amounts of food be produced per unit of distributable irrigation water available.

Water resources can be conserved through pricing policies. Workable price schedules with penalty rates have been evolved in other countries where it is to the good of both the cultivator and the public to discourage overirrigation. There is no doubt that appropriate schedules can be devised in India whereby cultivators can be provided with water at reasonable costs up to the point of real plant needs. Prices per unit volume would increase sufficiently thereafter so as to make overirrigation less profitable than optimal irrigation. Thus, good management can be substituted for overirrigation without penalizing profits for the individual.

Obviously, a well-thought-out research project will be needed to provide the basic data from which public policies can be formulated. As a starting point the subject of volumetric sales of water has been considered seriously by working groups in association with national planning in irrigation matters. [p. 7 (Ref. 9)], [pp 21, 64, 65, 66 (Ref. 17)].

Sources of Irrigation Water

Major river valley projects—The history of irrigation in India dates back many centuries. Some of the existing major canals like the Western Jumna Canal were originally built by Mughal Emperors but most of the extensive irrigation systems were constructed during the British period.

In the past, irrigation development was undertaken primarily as a famine relief or a revenue source. The projects and most of the irrigation works were designed with these objectives in mind. Agricultural considerations were often subordinated with the net result that many projects do not adequately meet the current needs of a modern cultivator who wants to maximize his agricultural production. In such circumstances many irrigated areas within the command of a canal are obtaining supplemental water from sources such as tanks, reservoirs, and wells of all kind. In fact, it is estimated that tanks plus wells contribute about equally with canals toward the total irrigated acres of the country (Appendix 6).

The importance of irrigation to the national welfare requires that methods be developed which will assure its permanency. Large sums of money have been invested in scientific farming, in creating the storage reservoirs for both irrigation and power generation, and in developing and maintaining the many smaller irrigation works. The life expectancy of all works, but especially that of the major ones, must not be unduly shortened by excessive flow of silt and sediment from the catchment areas.

The development of a healthy and permanent irrigation systems involves a number of complex management practices. These need to be revised and up-dated to meet the requirements of production oriented modern irrigation agriculture.

Suitable soil conservation practices need to be developed, and applied. The effect of soil conservation measure on the runoff and sediment production needs to be thoroughly researched under India's various agro-climatic conditions. The source of silt needs to be studied and contributions from cultivators fields and from stream

banks and channels need to be identified so that appropriate control measures based on scientific data can be taken.

The many irrigation projects undertaken in recent years form a part of a vast complex of multi-purpose river valley schemes. Some of the larger ones (costing more than Rs. 300 millions each) are shown in the following table :

Some Major River Valley Projects in India*

	Total cost (Irrigation portion only) Rs. million	*Gross area to be irrigated on completion in '000 acres*
1. Bhakra-Nangal (Punjab & Rajasthan)	1,018.9	3,604
2. Chambal (Rajasthan & Madhya Pradesh)	548.5	1,400
3. Damodar Valley (West Bengal)	346.8	1,273
4. Gandak (Bihar & U.P.)	494.5	3,138
5. Hirakud including Mahanadi Delta (Orissa)	933.4	2,158
6. Mahi (Gujarat and Rajasthan)	471.8	751
7. Nagarjunsagar (Andhra Pradesh)	911.2	2,060
8. Rajasthan Canal (Rajasthan)	664.7	1,684
9. Ramganga (U.P.)	345.5	1,705
10. Tungabhadra (Andhra Pradesh & Mysore)	575.3	1,030
11. Narmada (Gujarat)	430.9	963
12. Beas (Punjab & Rajasthan)	1,174.3	2,630

Tubewells and open wells—Wells furnish water for nearly one-third of the total irrigated land in the country. These are most

*Presented by Baleshwar Nath, Member, Irrigation Team, Committee on Plan Projects, Planning Commission, Government of India, New Delhi, in a Lecture delivered at the Indian Agriculture Research Institute, New Delhi on March 25, 1966.

prevalent in Uttar Pradesh, Punjab, and Rajasthan and to a lesser extent in alluvial pockets and coastal fringes in other states (Appendix 6).

Because wells tap aquifers which in turn drain the overlying underground reservoir as their source of water supply, it follows that in areas of high water tables, wells can be effective as a means of lowering this level. Basically, the consumptive use of the cropped area represents the magnitude of groundwater decrease that can be effected by such pumping during the cropping period.

Ideally an equifer should be as high as possible for economy in well installation, but deep enough to maintain water flow into the aquifer without causing waterlogging in the root zone of crops.

All open wells belong to individual cultivators. Government or the Cooperative Banks often provide financial assistance. (Ref. 16, p. 11). Open wells are either dug or sunk from the ground surface into water bearing aquifers. Care must be exercised to assure that well linings or screens do not "seal off" the aquifer and that sufficient infiltration can take place through the lining without undesirable loss in pressure head.

Because open wells are generally of the "shallow" type, they are more vulnerable to fluctuating water tables and sometimes require restoration by deepening.

Tubewells offer excellent possibilities for providing irrigation water and drainage simultaneously. In areas where the water table is high and the water quality good, the dual role of a tubewell has much to recommend it. Properly designed with due recognition to water source, a tubewell should provide assured water supply almost at the will and convenience of the water users. The cost per unit of water is generally higher than that of canal water. This greater cost provides an incentive for efficient conveyance and water use.

In West Bengal we were informed that tubewell development combined with underground conveyance pipe was predicated on the fact that underground pipelines not only deliver water with minimum loss but also permit utilization of the land overhead for crop production.

Open well and tubewell construction should be encouraged in certain waterlogged areas in order to supplement primary gravity sources to irrigation water and to reduce the waterlogging potentials of the primary source. Shallow tubewells or open wells are especially suited for this purpose.

Theoretically, wells should be efficient sources of available water because they are directly under the cultivators' command and are located near the irrigated crop. They require only short and small conveyances and distribution systems. In spite of these apparent advantages, many of the minor irrigation tubewell installations have neither commanded their total areas nor have their working hours come up to expectations (Ref. 17, p. 11). The potential benefits of minor irrigation deserve that these problems be studied with the objective of utilizing the inherent potential of tubewells to the fullest. Pilot schemes for investigation of causes for under utilization of tubewell water and possible improvement should be considered.

Research needs: Research is needed on construction of shallow wells. Ideally, the well lining should act as an effective mechanical barrier for silt and sand without retarding the flow of water from the aquifer into the well.

The existing work on improving the water yield from wells should be expanded, particularly on tubewells, on gravel packs and related innovations. Reasons for under ultilization of tubewells need thorough study with the view of taking corrective measures. Water balance determinations, similar to those considered so necessary for major river valley projects, are equally important for the tubewell systems.

The command area of many tubewells seems too large for the water pumped. An assured adequate supply is a basic necessity to encourage the necessary agricultural inputs on irrigated land. In this respect the number of hours that the well is not functioning needs investigating. The full irrigation water potential cannot be utilized, nor the potential command area furnished water if preventable failures continue to plague the cultivator.

Though there is much to recommend the standardized 5-horse-

power electric pumpsets, the use of both larger and smaller pumpsets and other lifting devices should be investigated. Guidelines to aid in the selection and matching of suitable wells and lifting devices need to be developed in order to maximize water yield and use and minimize cost. Different types and sizes of wells and lifting devices suitable for areas of various ground water supplies should be included.

The flow characteristics of wells and aquifers need to be evaluated in the field. On the other hand, the operating characteristics of lifting devices and power supplies are far less affected by site conditions. In fact many characteristics are practically independent of the site, and results obtained for industrial, municipal and other purposes in India and elsewhere can be extrapolated to agriculture with a minimum of modification and risk. The main problem is finding a suitable basis for matching the available ground water, well, and lifting devices permitting the establishment of guidelines for application to agriculture.

Improved methods of lifting water from open wells are needed. Existing methods adaptable to local conditions should be investigated for possible improvements. For example, an undesirable feature of the chain-and-bucket type of Persian wheel is that the water is lifted considerably above the surface of the land before it is dropped from the buckets into the receiving trough. This extra lift represents an appreciable percentage of the power requirement, especially where the water is close to the surface.

The above situation led to the development of a number of adaptations of the Persian wheel principle. Especially noteworthy is the *sakia* or all metal wheel with volute-shaped compartments open at the periphery of the wheel with a central opening around the axis. (Ref. 13, p.30). This adaptation reduces the power requirement, permitting the bullocks to work easier or possibly longer without any reduction in water output. It is quite possible that further improvements can be made, even though the big improvement often is an electric driven pump.

Diversions:—One of the least expensive ways of obtaining

irrigation water is to divert it from a stream and convey it directly to the adjacent irrigable land. These schemes generally consist of temporary weirs or diversions in the stream which raise the water level sufficiently to divert it into a conducting channel.

Diversion schemes range considerably in magnitude up to large permanent structures. In many cases the improvised obstructions used in small streams usually in hill or mountain areas, require major repairs or rebuilding almost every year usually after the monsoon floods. There is opportunity for considerable improvement in the planning and development of small-scale projects. Since these latter generally have not involved very great expenditures from government agencies they have not always received adequate planning or design consideration. The hydrology of the watershed, primarily the period and direction of low flow should be considered before heavy investments are incurred which can be jeopardized by insufficient water supplies.

The same standards for assured and adequate water supply apply to large diversion projects. Since diversions generally have no provision for storage, their success depends on the streamflow at the time of peak irrigation needs. The water balance of the streamflow and the anticipated area to be commanded at given times must be analyzed for feasibility of the project in terms of meeting real irrigation needs. Diversions vary in the intensity of irrigation provided from those that provide water continually to those that may function only during the monsoon period.

Tanks—India's Unique Tool for Irrigation—Among water management devices in India, the importance of tanks can hardly be overestimated. These traditional monuments to the hoe and head beasket can only be understood by temperate zone visitors in the light of climatic events dictated by the monsoon which strikes India's southern tip in late May or early June (Ref. 16). The distribution of tanks and their usefulness results from the monsoon's rainfall pattern which deposits 15 to 30 inches on northwest India in a $2\frac{1}{2}$ month rainy season and up to 120 inches along the southwest coast with a 4 to 5 month monsoon.

The Indian cultivator, having lived under the monsoon-dominated weather pattern for many centuries, has devised and constructed tanks throughout the subcontinent. In 1960-61, 11.20 million acres or 18.6% of all irrigation was ascribed to tanks as compared with 22.45 million acres from government canals in the medium and major irrigation systems.

Tanks are considerably more important to some States than to others. In descending order of net irrigated area from all water sources in 1960-61, the relative contribution by tanks within the several States as calculated from data from pp. 42, 43 (Ref. 16) is as follows: Orissa, 50.8%; Mysore, 40.0%; Andhra Pradesh, 39.6%; Madras, 38.8%; Maharashtra, 28.0%; West Bengal, 27.2%; Madhya Pradesh, 15.9%; Bihar, 15.4%; Rajasthan, 9.4%; Kerala, 9.0%; Uttar Pradesh, 8.3%; Gujarat, 1.9%; and Punjab (Haryana), 0.1%. Canal irrigation dominates in the semiarid, flat Punjab region.

Tanks may be privately, cooperatively, or State owned. Generally, if they command an area of more than 200 acres, they are supervised by the State Department of Irrigation. There is perhaps nothing typical about a tank as to size, shape, depth or form. The one thing they all have in common is that they were located, built and used to catch water for use in the long dry season between annual monsoons. Amazingly, the agricultural effectiveness of these tanks of India compares favourably with master engineering works. Even though the amount of water stored for later use is small for each tank, water distribution problems are minimized because the water is used next door to the storage basin, and the tanks are numerous.

In many tanks, topography precludes the utilization of the full tank capacity for irrigation. Considerable water, below the outlet elevation, remains unused. In areas where water supply is critical, an open well in the vicinity of the tank or some other way of tapping the water below the outlet elevation or even the ground water below the tank itself, my provide water for an otherwise dry period.

Tanks are inherently vulnerable to heavy evaporation losses, siltation, and limited storage volume which often is depleted before the crop matures. Tanks occupy land which in many cases could be used

for agricultural purposes. It is desirable, therefore, that the above factors together with the water yields and characteristics of the watershed be considered in evaluating the tank and the agriculture dependent upon it.

Recommendations for the Fourth Five-Year Plan on Minor Irrigation call for legislation to protect tanks from silting. Punitive taxes would be imposed "to stop the practice of foreshore and bed cultivation of tanks" (p. 10 par. 10) (Ref. 16); soil conservation measures are proposed which would diminish tank silting under Water Conservation-cum-Ground Water Recharging Schemes (p.18) (Ref. 16); percolation tanks primarily for the purpose of recharging ground water are said to be in vogue in Maharashtra, Mysore, Madras, Kerala and Rajasthan; and Rs. 336.8 million for new tank and reservoir construction along with Rs. 432.2 million for restoration of old tanks and reservoirs, for a total of Rs. 769.0 million are proposed for the Fourth Five-Year Plan. By comparison, Rs. 373.8 millions are estimated for the development of 17,665 tubewells in the combined public and private sectors during the same Five-Year Plan.

These facts and figures are cited by way of emphasizing not only that substantial governmental recognition through legislation and financing is being given to tanks in India, but also as a reminder that support for research on these important structures seems not to have materialized—at least in any formal way and certainly not in any proportion to research funds devoted to other water systems.

There are other goals whereby collaboration between soil and water science, engineering and landscape architecture might evolve improved practices of benefit to land and water management. Consider India's widespread brickmaking industry and its relations with agriculture. Thousands of acres of productive agricultural land in India have been despoiled by the brick industry and irrevocably put out of use for production of food.

In the case of excavations left by brick manufacturing, we believe that if these present wasted scars on the landscape were to be converted purposefully to combined tanks and surface drainage channels, that they might become even more useful to the community

than they were as agricultural land. Also, there are the borrow pits. Should these not be integrated with tanks made from abandoned brick pits and surface water drainage systems by converting the borrow pits to graded channels with catchment leads into the converted pits serving as tanks? Here we would call on the building materials research people, for example at the Central Building Research Institute, Roorkee, U.P., to locate sites having soil good for making bricks to a depth of 10 or 15 feet or more. With this depth the brick pit could later become a more effective tank.

It is urged that agriculture solicit the support of Departments of Public Works, drainage sections of Departments of Irrigation, the Central Building Research Institute and landscape architecture to arrive at integrated solutions of both water conservation and surface drainage problems wherein brick pits and borrow pits might be used to restore surface drainageways that have been blocked by elevated roadways etc. It is proposed that brick pits be made as deep as possible and then be converted to tanks after abandonment.

From points of view in land and water management, so many questions have arisen among team members about the present and potential role of tanks in India's water resources picture, that it is in order to present some of these.

(1) What are the relative benefits from multiple uses of tanks as a source of water for domestic purposes, for animals and irrigation ?

(2) There are numerous potential sites for catchment and storage of water which have not been exploited. Could specialists rate such sites in terms of potential usefulness as tanks ?

(3) Has anyone studied the soil-water interrelations beneath tanks on different soil types; or the factors governing seepage through dams versus bed penetration ?

(4) Cannot the excavations made by brick manufacturing activities be integrated with programs of tank construction ?

(5) Do tanks recharge underground aquifers ? If so, to what degree and when and where does the water reappear for further

exploitation ? What are the rates of recharge by seepage versus rates of loss by evaporation from the free water surface ? How does recharge from tanks compare with that from rice fields which are far more extensive during the monsoon period of high water availability ?

(6) Are there simple rules for tank maintenance which can be worked out founded upon basic principles and experience to be followed so that the life of tanks can be extended ? Can saved maintenance labor be transferred to other work which would enlarge tank storage capacities ?

Recharge of underground aquifers—Pumping from wells can only draw water temporarily unless the underground reservoir is recharged. Ordinarily, the ability of underlying aquifers to resupply water can only be evaluated through experience coupled with geological understanding of subterranean features of the surrounding country. In India, at the present time, deep tubewells are being interspersed with shallow Persain wells so that new pumping regimes are superimposed upon the old. Also, new wells are tapping underground reservoirs where no wells existed before.

Three large questions face everyone concerned with future well development : first, what is the quantity and quality of water immediately obtainable through investment in wells and pumping sets ; second, what are the costs of lifting unit amounts of water from the underground reservoir, and third, how long will the underground reservoir continue to deliver ? The first two questions are being answered quickly from early experience and by exploratory test bores. Test bores from tubewell explorations can also be made to provide clues about underground strata—their distribution, hydraulic conductivities, and the geological circumstances under which the strata were laid in place. Information coming from a single test bore is not too significant by itself, because the core samples taken may represent only a sequence of lenses rather than extensive strata. However, the value of test bore information increases steadily with the number of borings made. Where optional development of an underground water resource is sought, skilled geologists should be given the responsibility of

correlating all findings which may come from test bores and subsequently from the wells after they are placed in use. Unless this is done, the third important question regarding knowledge of size, recharge characteristics, and life of the underground reservoir will remain nebulous and a matter of divergent opinions.

The ultimate understanding of natural underground hydrology must include rates of recharge, routes of recharge, and quantity of recharge water available. In reaching positive conclusions every bit of drawdown and recovery information which can be made available from individual wells will assume importance, particularly in the early stages of tubewell development in a newly tapped area.

Two instances are cited of the kinds of findings that bear on underground water resource evaluation relative to recharge characteristics. In Madras (Coimbatore area) there are masonry-walled dug wells which have required progressive deepening with passing years as cultivators followed receding water levels downward to depths as great as 75 feet until further extension of dug wells were no longer practical. Some wells were abandoned ; others were bored deeper (250-300′) until a water bearing acquifer was reached. This experience suggests that these wells were tapping an underground reservoir whose recharge rate was insufficient to meet withdrawal. Had there been full records of dates of tapping for each of the wells and water levels encountered at that time, with subsequent knowledge of the amounts of water removed by each well, data would be available from which informed conclusions could be drawn regarding natural recharge characteristics and the pool size of the underground reservoir. Later, when the wells were bored to greater depths, additional information could have been provided for the same pool. Gathering data of the kinds suggested is important because recharge rates may or may not improve with depth of water table, depending upon circumstances where the head responsible for rate of recharge may be increased as the water table falls. Thus, in matters relating to policy on the very live issue on number of wells permissible per unit area, understanding of recharge phenomena assumes high importance.

A second illustration is taken from the Gangetic Plain in Bihar

where depths of water table have been observed for each month of the year both in areas where irrigation has been practised for 80 years (Bikramganj) as against ground water tables where irrigation has just begun (Madepura). In both cases a maximal water table level is reached in September-October, at 4 to 5 feet below ground surface. Then the table declines gradually until mid-June at which time it has reached about 20 feet at Bikramganj and about 10 feet at Madepura. Suddenly in mid-June, both sites show water tables rising very rapidly, again reaching maximal level in September-October. Interestingly, the sharp rate of water level increase occurs before onset of the monsoon. At first sight it would appear that the changing water tables and their seasonal patterns must result from freely conducting underground strata charged by the annual monsoon. But, neither the points of entry of recharge water nor the outlets are known. Pumping cannot account for 10-to 16-foot annual drops of water table, nor can irrigation explain the rise. We have found no concerted effort being made to evaluate the underground hydrological aspects of wide geological areas such as the Gangetic Plain.

These two extreme cases are given to illustrate agriculture's stake in research leading to understandings of the nature of underground water resources in different localities. Active, continuing research on underground hydrology is called for wherever changing underground water patterns are being induced by irrigation, whether the problem is one of rising water table with waterlogging potential, or drying wells which fail to recharge.

In India, with its short period of monsoon rainfall and long dry season, a high premium may be placed upon soils with high infiltration rates as potential sites for entry of recharge water which might be captured from the monsoon. But soils with high infiltration characteristics are also subject to more rapid waterlogging if the underground reservoir does not have an outlet. Feasibility studies should be initiated on waterlogged areas as sites for underground reservoirs. Such areas have already demonstrated water storing capability. So if drainage is undertaken and the quality of drainage water is satisfactory for agricultural use, a two-pronged agricultural objective would be served by a combination of drainage of waterlogged land coupled with irrigation

of additional land which is water deficient but which does not have a drainage problem.

Underground water recharge potential will always be an attractive feature of any natural or artifical depression which can capture some or all of the flush of monsoon precipitation. Losses by seepage need not be entirely bad if such losses can be regained readily from wells at reasonable costs at a later time and the seeped water does not adversely affect crop production. In fact "seepage" might be good if it can be considered as "recharge" because underground reservoirs are the only ones protected entirely from evaporation losses. India has schemes for soil conservation and ground water recharge wherein it has been suggested that there is excellent scope for undertaking soil conservation measures in conjunction with minor irrigation constructions through "increasing recharge of groundwater" (pp. 70, Ref. 16). Presumably, water saved from runoff will reappear elsewhere in wells, tubewells, tanks, etc. Further emphasis is given to development of means for recharge through "percolation tanks, rapats, bundhies, ahars, etc." (pp. 120, par 12.11, Ref. 16).

All of these suggestions are fine as generalities, but more is needed if earnest public support is to be attracted toward significant water recharge projects. Where soil conservation is the main objective, water recharge can be viewed as an important fringe benefit. However, if the recharge contributions could be measured and evaluated, considerable power might be added to arguments for soil conservation activities.

The points which must be made at this time are simply that details of water recharge are very difficult to assess in quantitative terms. The puzzles of underground hydrology differ for every geographical circumstance and no two are alike. However, the principles of water flowing through porous media are the same for soils as for underground subsoil formations. What is needed for tackling hydrological problems of direct concern to irrigation agriculture is a close-knit enterprise between soil physicists, soil conservationists, underground hydrologists and irrigation and drainage engineers which can examine hydraulic properties of both surface soils and underlying

deep subsoils as integrated whole systems. Only in this way will it be possible to cover all of the physical aspects of recharge which must be weighed against withdrawals when predicting the life of underground water reserves.

Some underground recharge can be accomplished whenever water is leached below the root zones of plants. The leached water is the excess over consumptively used water which is stressed elsewhere in this report. Water lost below the root zones by seepage may be recovorable later at outlets for underground drainage by pumping from wells. Many shallow wells presently in operation may be depending largely upon seepage water which passes below root zones during the rainy season. Others may be tapping aquifers charged by adjacent rivers, streams or nallas, depending upon individual circumstances of the well and its recharge connections. There is no way to tell a priori how a well abtains recharge water except to study the well in relation to its hydrological environment.

The conditions affecting depletion and recharge of underground aquifers are great and the competence to study, understand, and classify such systems lies in the province of hydrologists specializing in underground transport and storage. A start in underground hydrology research should be made in India as a means of augmenting the needs of irrigation agriculture to gain an understanding of water resources provided by wells and their recharge characteristics.

For a comprehensive appraisal of ground water available for development in the Upper Gangetic Plain, as well as a suggested investigational and developmental program for optimum use of these water resources, the reader is referred to the recent pertinent report of Jones and Hofmann (Ref. 10).

Seepage of Water from Conveyance and Storage Structures

Losses of irrigation water by seepage—Large quantities of water harvested from watersheds, pumped from ground water sources, or diverted from streams, are lost each year from storage and conveyance facilities through evaporation and seepage. In most cases, the greater losses are by seepage.

It was reported that in 1960-61, 1.1 crores (11 million) of acres were irrigated from tanks (see Ref. 16, pp. 43 and Appendix 6). In addition there are uncounted thousands of tanks providing water for domestic and animal use. Most tanks receive their water from runoff during the monsoon and provide storage for domestic water throughout the year. The lack of favorable sites has resulted in the building of many tanks whose upper and lower surfaces are large in proportion to storage volume. Larger proportions of surface and submerged areas per unit volume result in larger water losses from evaporation above and seepage below. Both would be lessened if this proportion were lowered.

As water is conveyed to irrigated lands by open conveyance channels additional opportunities are provided for seepage and evaporation losses. Over half of the irrigation water developed can be lost through evaporation and seepage from tanks, canals, distributories, waterways and ditches.

Because the economic significance of seepage losses has long been recognized, many major and minor canals and ditches have been lined or replaced with impervious conduits. Decisions on needs for lining are based largely on economic analysis and much information is available on the reduction of water losses that may be obtained through the use of different types of lining installations. In some cases not only is the loss of seepage water of concern but the damage that it creates by waterlogging and/or salinity is considered. The designer of irrigation systems may choose to provide adequate drainage systems to prevent such damage or to reduce the seepage to tolerable amounts. Very often the drainage aspect is overlooked or neglected in the interest of initial project costs.

While it is recognized that each site presents a different problem with respect to seepage, methods of evaluating seepage from unlined channels or reservoirs are poorly developed. Nevertheless, estimates of seepage are needed if corrective measures are to be planned on a rational basis. Some attention should be given to means of evaluating losses from existing channels and associating these losses with factors such as the texture and layering of soil materials, depth to water

table, size and cross section of the channel, depth of flow, and other factors.

Waterlogging and salt associated with canal systems— Indian canals carry large volumes of water over long distances. They are in operation for most of the year. Rising water tables are noted in many places where canals have been in operation for some time. In other instances, as at Kota where water was first delivered six years ago, the rise has been very rapid and drainage projects have been started to lower water tables which have appeared most prominently adjacent to the canal route.

In sections of the country more subject to waterlogging, damage shows first along canal routes. Bands of such land are easily visible along each side of canal systems in the Punjab-Haryana regions. From the air, these strips are prominently displayed by sharp vegetative changes as compared with land further removed from canals. Widths of damaged strips vary from a few hundred yards to a mile or so. By implication, it is the seepage loss from the canal which creates the pattern.

Water levels within canals are higher than the surrounding territory so that water mounds build up beneath them and then by lateral flow move away from the canal at right angles. This process wets the soil at lower depths before it reaches the soil surface so that the water table now rising from below, flushes salts upward. The advancing front of the rising water table dissolves soilborne salt which may be present in reasonably low concentrations in the soil. However, as the advancing front is moved slowly upward, the salty upper layer of water dissolves still more salt, so that by the time the upper water layers reach maximal height near the soil surface their salt concentration is too high to be tolerated by crop plants. The same process occurs in distributories and ditches but to lesser degrees.

These damaging influences from canal seepage are additive to waterlogging problems induced by overirrigation of the land. The only lessons to be learned are that seepage is doubly undesirable, first because water needed for irrigation is lost, and second because the lost water creates salt damage.

Solutions for both problems lie only in perventing canal seepage. If this is impracticable, the cost of unlined canals should be calculated in terms of land damages which are to be added to initial construction costs. If this is done, it will no doubt be revealed that for many instances the cost of good canal linings will be cheaper than having leaky canals and distribution systems.

Weed problems in canals and ditches—Weed growth in canals and ditches presents two major undesirable features to water conveyance operations, namely, the obstruction to water flow and spread of weed seeds to cultivated fields. Growing plants hold back water flow in greater proportions than implied by reduction of cross section of conveyances because small turbulences consume energy which otherwise would be used in moving the water mass.

Also, seepage losses are increased to some extent because as the flow rate is decreased, the head of water increases. On smaller ditches and conveyances the size of weeds can become so large in proportion to the channel that transpiration losses become quite important.

Maintenance costs for weed removal are high in monetary outlay and the shutdown time causes inconvenience if not real loss to some cultivators. Proposals for the use of weedicides face special complications in India because canal waters are important sources of drinking water for animals and for domestic use.

Weed growth is but another feature which speaks strongly in favor of studying all of the economic factors involved in the running arguments that lining materials are too expensive for general use.

Canal lining materials—At several of the locations visited experiments were being conducted with several types of canal linings in facilities specially constructed for measurement of seepage losses. This important work should be encouraged, but it is believed that the results would be more valuable if the work at the various locations were better coordinated and the results gathered together for release in a single report.

Since the effectiveness of canal linings can be greatly reduced by mechanical damage, deterioration with time, and the soil materials

upon which the lining is laid, it seems that an evaluation of seepage losses through linings which have been in use for sometime would be helpful in determining the savings of water that might be obtained by these different types of installations.

Under field conditions, few linings are perfect and water losses through cracks can be significant. Thus, seepage measurements on field installations should be accompanied by thorough descriptions of the conditions of the lining together with complete description of the soil and soil conditions during the time the linings were constructed, the date of installation, construction method, and a brief account of any later maintenance or repair work done.

Seepage at these installations can be measured by ponding methods, but care must be exercised in selecting the test area and the length of the reach tested must be sufficient to truly represent the field condition.

Another recommendation relating to seepage measurements for different lining materials, is the need for reporting the data on a more absolute basis. In most instances observed, the effectiveness of lining materials were reported in terms of percentage of water saved per unit area of water surface in the canals or per unit area of wall or bottom of canal exposed as compared with losses from an unlined channel. Since substrata and soil conditions of unlined channels vary widely from location to location throughout the country, the base used for computing the percentage of water saved is highly variable and, as such, percentages of water saved by the same lining material at different locations could be more a function of the permeability of the unlined channel than of the lining material under test. Summarizing data for the same lining material under differing soil and site conditions at different locations would appear suspect.

It is recommended as a part of the above mentioned coordinated approach, that a canal lining material such as concrete which allows a minimum of seepage to occur, be used as the standard at all test locations for comparison with other materials.

The measurement and compilation of such data from points

throughout India, if made readily available to those charged with planning, construction and maintenance of irrigation projects, major and minor, public or private, could do much toward conserving valuable irrigation water resources.

Recommendations for Implementation of Research on Irrigation Water Sources

The many comprehensive and difficult problems relating to sources of irrigation water and its transport to the farm suggest a highly imaginative research approach involving people having training and experience in a wide array of disciplines, and necessitating interdepartmental and interagency cooperation and collaboration both at the Center and State levels.

Delivering water from source to cultivator fields as enumerated, presents several complex problems and it is, therefore, recommended that pilot research projects be initiated :

(a) Whereby full case histories of water transmission and use from single-outlet command areas can be studied and reported in quantitative terms of real water use by cultivators of small holdings. This will include an accurate measurement of water coming into the command area and accurate measurement of water actually spread on each holding. The difference will reveal channal losses and channel efficiencies at the practical level.

(b) Whereby studies can be made of cultivators' organizational resources which could provide for equitable methods and rules for water distribution within a single outlet command area.

(c) Whereby selected command areas will be offered water for purchase on rate schedules based on volume delivery to encourage full water utilization and to discourage over-irrigation.

(d) Whereby selected wells be studied as to problems of well design, construction and maintenance, including materials and equipment and evaluation of pumping costs.

Recommendations for research on water use and soil management problems of Major River Valley Projects and Command Areas of tubewells and open wells, are given in the following sections: pages 57 to 59 and 75 and 76.

Tanks as catchment and storage structures for domestic, animal and irrigation water supplies are a resource of substantial importance in India. Recommendations for research include:

(a) Recognition that research attention is needed on tanks which will provide information on storage efficiencies under different climatic belts and for different soil groups in India.

(b) A study group to be formed with inter-disciplinary and inter-agency representation which will be charged with planning the scope of investigations as they might touch upon Minor Irrigation, Community Development, Department of Public Works, Soil Conservation, Central Building Research Institute as agencies, and include sociology, soil science, civil engineering, agronomy, climatology, forestry, animal science, geology, limnology and water science as representative disciplines. The study group would be asked to report upon benefits that might accrue from research studies of tanks in relation to improvements which could contribute to India's economic development and to make recommendations for practical ways in which to get an effective research program started. Based on the study group's deliberations, an appropriate budget and research should be established.

Recharging underground aquifers should receive research attention, the recommendation for which is :

That a minimum of three projects be established to study problems of recharge of underground aquifers to be located at Agricultural Universities, Center Institutes, or other qualified institutions near the principal irrigated regions. One should be centered in a coastal high rainfall environment where soils are highly leached and approach flooding conditions annually. A second should be designated for the

Gangetic Plain where tubewell development is expanding rapidly. The third should be located in a typical rainfed upland area where recharge of aquifers supplying the smaller and shallower wells is an important consideration.

Seepage losses of water from storage and conveyance channels are exceedingly large in India and represent not only a serious loss of precious water needed for food production but cause waterlogging and salt problems in varying degrees along canal or storage structures.

Recommendations include:

(a) A research study on costs of canals, ditches, and cultivators' conveyance channels which will evaluate the contributions of (1) damage to land from seepage, (2) losses of water from seepage, (3) maintenance costs for weed removal and (4) estimates of damage from weed infestations. The cost estimates discovered from these studies should be compared with capital costs for lining conveyance channels as amortized over periods of 10, 15, 20 and 25 years.

(b) A pilot research project in command areas involving tests and evaluations of lining materials for ditches for conveying water to cultivators' fields. This would involve a series of different linings, proven to be most effective in reducing seepage from larger channels at experiment stations, installed in various reaches of farmer's ditches used for irrigation. The research would evaluate costs of preparing the subgrade and installing the lining, measurement by the ponding method of the relative effectiveness of reducing seepage losses of the test linings at periodic intervals after date of installation, and observations on deterioration of linings and costs of maintenance and repair.

(c) Active consideration by the ICAR of possibilities for chemical control of aquatic weeds within the realization, however, that India's water distribution systems pose special problems involving domestic and animal use of water as pointed out in Appendix 7.

Consumptive Use and Irrigation Water Requirements

Enlightened water management can function effectively only upon a broad base of scientific understanding of the soil-water-plant phenomena. A body of basic water use data is needed for effective design of irrigation projects and subsequently in the day-to-day and season-to season water management operations at the farm level.

The water distribution system and the crop needs must be intimately interlinked so that the entire complex may function purposefully and harmoniously for maximum food production efficiency.

In studying the research needs in soil & water management, the Team has depended upon certain definitions and terminology for preparing the recommendations relative to obtaining solutions for land and water management problems. Some of these are indicated below.

Terms and definitions—

Consumptive Use is the amount of water used by the vegetation through transpiration and evaporation from the adjacent soil and plant surfaces (evapo-transpiration) plus the amount used in photosynthesis.

Peak Period Consumptive Use is the average rate of water used by a crop during the period of maximum use.

Consumptive Water Requirement is the amount of water required to meet the consumptive use of vegetation in a specific area so that plant growth is not limited by lack of water.

Net Irrigation Requirement is the depth of irrigation water, exclusive of precipitation, stored soil moisture, or ground water, that is required to meet the consumptive water requirements in producing a satisfactory crop, as judged by local standards, plus that required for other related uses such as leaching and temperature control.

Unavoidable water losses due to runoff, deep percolation losses in the field, plus conveyance losses in delivering the water to the field must be assessed and added to the net irrigation requirement to obtain the Irrigation Water Requirement.

Some factors influencing water use—Many factors operate singly or in combination to influence the amounts of water consumed by plants. Their effects are not constant and may differ with locality and fluctuate from time to time. The more important influences are soil, soil fertility, climate, water supply and plant growth characteristics.

A discussion of some of the measurable factors that contribute to water use follows.

Radiation : The consumptive use of water by crops in any particular locality is probably related more to net radiation than to any other single factor.

Air Temperature : Temperature is a reasonable indicator of integrated incident solar radiation over a long period of time.

Humidity : Evaporation and transpiration are accelerated on days of low humidity and slowed during periods of high humidity.

Air Movement : Water evaporates from both land and plant surfaces more rapidly when there is moving air than when the air is calm. As soon as a land surface is dry, evaporation practically stops. But transpiration continues, though it is limited by the ability of a plant to extract soil moisture and convey it through the plant as the soil moisture is decreased toward the wilting point.

Advection : Crops grown in irrigated areas surrounded by large arid or semiarid areas can receive additional energy for water vaporization through advection. This is known as an "oasis" effect. Such evaporation of water by vertical turbulent transfer can cause a considerable increase in consumptive use in arid areas, but has practically no effect in a humid environment.

State of Plant Growth : Except for crops grown under flooded conditions, such as paddy, the stage of a crop growth has a very large influence on consumptive use. This is particularly true for annual crops which generally have rather distinct stages of growth and maturity. These stages may be delineated as follows:

(1) The period between emergence and development of the comp-

lete vegetative cover, during which time the consumptive use rate increases rapidly from a low value and approaches its maximum,

(2) The period of maximum vegetative cover, sometimes referred to as full canopy, when the consumptive use may be near or at its maximum, and

(3) Crop maturation, particularly with cereal crops, when the consumptive use rate decreases rapidly. Consumptive use falls sharply when a green crop is harvested.

Latitude and Sunlight : A longer day may allow transpiration to continue for a longer period each day and thus produce an effect similar to that of lengthening the growing season. Cloud cover decreases the amount of incident solar energy and thus decreases temperature and consumptive use.

Soil Fertility : If the soil fertility is increased by the application of fertilizers or by some other means, the yield may be expected to increase with an accompanying increase in water use. However, this increase is so small that it is seldom considered when estimating consumptive use.

Estimating consumptive use—In areas for which few or no measurements of consumptive use are available, it is usually necessary to estimate consumptive use from climatological or other data. Such estimates must be based upon correlations, which have been developed elsewhere, between measured consumptive use and climatic parameters. The closest and best correlations developed todate utilize "net radiation" as the primary parameter. However, in India these data are not generally available and it will be necessary to use other parameters such as temperature, daylight or sunshine hours, humidity and wind velocity. Various coefficients relating these factors to consumptive use have been developed in many parts of the world but care must be exercised in using reported coefficients without reasonable checks on their applicability in the new environment.

Monthly or Short-time Consumptive Use Coefficients : Although seasonal coefficients as reported by various investigators show some

variations for the same crop, monthly or short-time coefficients show even greater variations. In India the principal climatic measurements that have been recorded for extended periods are maximum temperature, minimum temperature, wet bulb temperature, humidity, cloud cover, and wind velocity. Other pertinent factors such as the length of daylight and the radiation at the top of the atmosphere can be calculated from the latitude of the site under investigation. It becomes necessary to utilize these climatic parameters to determine the short period consumptive use estimates.

Methods which may be applicable in India for estimating short period consumptive use values include the radiation approach of Jensen and Haise (Ref. 8) and the temperature approach suggested by the U.S.D.A. Soil Conservation Service (Ref. 6).

Peak Period Consumptive Use : Information on peak period rates of consumptive use is needed to properly design irrigation systems. It is used to determine the minimum capacity requirements of main and lateral irrigation canals, pipe lines and other water conveyance and control structures. The peak rate of water use by crops also influences the administration of streams and reservoirs from which irrigation water supplies are obtained.

In irrigation project design, the peak period of consumptive use is the period during which the weighted average daily rate of consumptive use of the various crops grown in the project areas is at a maximum. Different crops may have their peak rates of use at different times. Therefore, some crops may not be using water at their maximum rate during the project peak period. In fact some of the crops may not even be grown during this period.

Factors influencing peak period use rate—While other factors may have a minor influence on peak period rates of consumptive use, peak period air temperature and net depth of irrigation application have the greatest influence.

Temperature : An analysis of daily mean temperature records for any month at any location will show that the mean temperature for the warmest consecutive 5-day period will be greater than that for the

warmest 10-days period. Likewise, the mean temperature for the warmest consecutive 10-day period will be greater than that for the warmest 15-day period and so on. All will be greater than the mean monthly temperature. Since consumptive use as estimated by a number of empirical formulas is greatly influenced by temperature, it is obvious that the shorter the peak period in days, the greater will be the mean temperature and, therefore, the greater will be the consumptive use rate.

The Net Irrigation Application : The length of the peak period is that number of days that a normal net irrigation application will last under the peak rate of use for the period. Thus smaller net irrigation application will last a shorter time and will result in greater peak period use rates. Conversely, greater net irrigation application will last a longer time and will result in a lower peak period use rate.

Research approaches—Consumptive use data are used in estimating the irrigation water requirements of existing or proposed projects or individual crops. The net irrigation water requirement depends not only on the total consumptive needs, but also on the amount of moisture contributed from such natural sources as effective rainfall, carry-over soil moisture, and any contribution from ground water.

A number of research approaches for determining consumptive use and water requirement exist.

The Depth-Interval-Yield Approach : This approach using different depths of irrigation applied at different intervals has a number of limitations primarily because these variables are fixed arbitrarily without making adjustments for soil and weather conditions. The arbitrarily fixed depth causes either underirrigation or overirrigation and the arbitrary interval results in either premature irrigation or delayed irrigation. Thus the crop is affected by excess water in some treatments and lack of water in others. In addition, very few records have been kept on effective rainfall and water table depth and their contribution to the tolal irrigation picture. The result is that trials using the above approach have only local application and are generally misleading when applied to more extensive areas.

The Soil Moisture Deficit Approach : Fixing the amount of irrigation on the basis of available soil moisture deficit is an improvement over the depth-interval-yield approach. Experiments of this nature have been in progress from 1956 onward at IARI and at certain colleges where suitable staff and equipment are available. Such experimentation is inadequate, however, considering the wide variations in the soil, water and climatic conditions of the country. The approach is satisfactory for all practical purposes. It does involve considerable expenditure of labor, time, and equipment. To make the experimental results useful in other areas, climatic parameters should be measured at the site of actual experiments.

Technical Manual No. 37-RR (B-1) August 1966, by the U.P. Irrigation Research Institute entitled "Water Requirements of Wheat" —says that the unique advantage of irrigation research at different soil moisture depletion levels is that it does away with the vagaries of nature—particularly rainfall. It continues that though "this mode of irrigation is gaining popularity in many countries, i.e., U.S.A., Australia, U.K. and others, shortage of technical know-how and lack of insured water supplies limit the use of this procedure in India".

Since this appears to be a basically sound approach to water management research, ways must be found for implementing the above approach in India. The skilled technicians and a reliable water supply for research purposes are within the realm of possibility. Such research is sorely needed to strengthen the principles underlying irrigation and forcefully focus attention on the need for an assured water supply adequate to meet peak demand of crops. Unless this is done, excessive and insufficient irrigation will continue until such time as convincing quantitative experimental evidence is obtained.

The above report also contains a figure showing the daily consumptive use by wheat during the 1965-66 season. It illustrates the basic type of data that must be obtained to provide a sound base for irrigation project design as well as irrigation application in the field. With this type of basic information the irrigation frequency, amounts and total can be readily determined. Such basic data also provide information on the magnitude and expected date that the peak water

requirement will occur. It is necessary that the procedure for developing these curves follow a technically accurate method and procedure.

Climatological Approach : According to some, the consumptive use of water by crops is governed primarily by meteorological parameters—that is, consumptive use is postulated as a physical phenomenon governed primarily by incident energy and only little by physiological processes of the plant. Furthermore, the soil is considered as governing only the depth and frequency aspects of irrigation. The greater the number of irrigations, the higher are the application losses such as evaporation and, therefore, the soil becomes one of the factors influencing the irrigation depth and efficiency. Consumptive use of water for the same crop grown on two different soils (e.g. a clay versus sand) is about the same for both soil types at a given location. However, the net irrigation requirements would definitely vary on the two soil types.

The climatological approach to consumptive use requires the recording of soil moisture changes throughout the growth period and correlating these changes with meterological parameters. Some believe that the climatological approach is simpler, more rapid, more reliable and has higher extension value than the soil moisture deficit approach. However, since the basic ingredient in both methods is the determination of the soil moisture changes within the root zone, once these soil moisture changes have been measured, subsequent computations to obtain consumptive use are relatively simple and consumptive use is easily calculated by either method.

Thus if an irrigation project is contemplated in a specific location, climatological data can provide the first approximation of water needs without involving soil moisture determinations.

Correlating consumptive use with pan evaporation offers a very effective way for extending consumptive use estimates to areas for which consumptive use data are not available. A map showing isolines of estimated annual consumptive use in India is available (Ref. 3 p. 13). This needs to be refined and additional maps prepared for shorter periods of time approaching the irrigation interval at peak consumptive use periods for different crops and for smaller areas.

Pan evaporation is one of the indicies available for estimating the consumptive use for paddy.

Irrigation of crops—

Rice : Despite the importance of rice in India and the diversion of 45% of available irrigation resources to this crop, very little attention has been paid to its water requirements. Available research information is misleading. The depth-interval-yield approach, whose limitations have been discussed previously, has very limited value in extending water requirement information to other areas. The technique for determination of water requirements for rice deserve further investigations and trials under field conditions (Ref. 3, p. 14). No one has measured seepage losses which probably form a substantial part of the total water requirement picture.

Some existing practices in irrigating rice result in excessive waste of water. Field-to-field irrigation as practiced for many years results in a late supply of water to the fields at the lowest elevation and the last field can get water only after the needs of those above have been satisfied. This system needs thorough study in order to develop practices and methods that permit irrigation compatible with scientifically determined soil-water-plant relations.

Whether submergence of land is necessary, and if so, to what extent it should be submerged, is an important question in the water management of rice. Additional work in irrigation during critical stages of plant development is also of vital importance. All these should be accompanied by quantitative measurements of the water required.

Wheat : Water requirement studies on wheat are relatively easier to conduct because of its shorter growing season and because, since it is grown primarily in the rabi (winter) season, it is less affected by rainfall. For these reasons more work has been done on wheat than on any other crop.

In the light of present knowledge of soil-water-plant relationship, experiments of the depth-interval-yield type should be terminated and replaced by the soil moisture depletion technique.

Studies during 1965-66 on the effect of different soil moisture regimes on Sonora-64 wheat—on the sandy loam soil at Pantnagar, U.P. —showed no difference in the yields of wheat whether irrigated at soil water tensions of under 0.8 atms. or 5 atms., or whether a single irrigation treatment was applied. The results were influenced by the considerable contribution of water from the shallow water table (Ref. 3, p. 24). These data emphasize the importance of a suitable site for effective consumptive use experimentation, and the undesirability of high ground water at the experimental site.

Many have correlated the consumptive use of wheat with evaporation from the U.S. Weather Bureau evaporation pan. The ratio of consumptive use to evaporation ranged from 0.52 to 0.56 in 1958-59 and from 0.41 to 0.54 in 1959-60. Another worker in studies at Udaipur concluded that type of vegetation and stage of growth did not affect water use by crops (Ref. 3, p. 28). This seems to be at variance with the prevailing concepts.

Maize : Very little work on water requirements of maize has been done in India. Maize is very sensitive to excess moisture and therefore has to be grown on ridges in areas of poor soil drainage or heavy rainfall on India's black soils. The seedling and flowering stages are very sensitive to excess soil moisture and yields have been reduced up to 50% by 4 days of soil saturation. It is also extremely sensitive to moisture stress during flowering stage and yields can be greatly reduced by inadequate moisture at that stage. Maize will probably become a crop of increasing importance to India and its special moisture requirements should receive early attention.

Groundnut : In India, the groundnut has been grown mainly as a kharif crop under rainfed conditions. Recently, however, its cultivation has been extended to rabi season under irrigated conditions particularly in southern India.

The groundnut is essentially a new crop with a great potential. However, unlike other commercial crops the fruiting body has rootlets of its own. These remain very near the surface of the soil and irrigation practices will have to take this fact into account. This is one example of the need for an active research program in soil and water

management which can take on new agronomic problems of importance to agriculture.

Improving irrigation experimentation—

(1) Irrigation workers should be appraised of the latest concept in soil and water-plant-climatic-relationship and related experimentation techniques.

(2) Studies on the variations in soil moisture under which the crop is being grown should form the most rational basis for a correct appraisal of irrigation requirements.

(3) Meterological data should be obtained at as many places as possible. Evaporation pans should be installed at all water use research locations and in all irrigated areas for guidance in water delivery. There is a dearth of weather data which will permit the drawing of correct and useful inferences for irrigation of important food and cash crops.

(4) Evaluation of the relationship between the consumptive use and pan evaporation should be expanded.

(5) Results of field experiments based on actual soil moisture conditions are likely to furnish more realistic information regarding the number and depth of irrigations, provided the trials remain in progress for number of years.

(6) It is equally essential that results obtained in different States be coordinated by someone at the Center level who should also keep watch on the progress of the work throughout the country.

Irrigation Efficiency

Problems in distributing and applying irrigation water to cultivated lands in India are greatly intensified by the typically large numbers of very small land holdings. This means that even a small irrigation stream system involving a great number of cultivators should be provided with a means of applying water in accord with each cultivator's needs and independently of the needs of his neighbors. Practicalities have forced many compromises.

In some areas, especially where rice is grown on terraced slopes, the lower fields are irrigated by overflowing water from the fields above. This arrangement eliminates most management options or choices available to the cultivator at the lower elevation and leaves him at the mercy of those in more favorable topographic positions. The downslope cultvatior may be left without water during periods of short supply and overly flooded during heavy rains. In some areas the water is delivered in open ditches at an elevation slightly lower than fields to be irrigated and cultivators are forced to manually splash or lift water to the crop. Only very rarely are fields provided both with adequate water supply and means for surface drainage. Underground drainage is exceedingly rare.

Many of the general problems of water distribution and drainage could be greatly minimized by providing better alignment of water courses and making available the necessary rights-of-way for adequate supply ditches and drains. The small holdings not only make it difficult to provide an adequate irrigation stream at a suitable elevation, but also greatly limit selection of irrigation methods which the cultivator can use.

Well-conceived land consolidation schemes may be the only logical first step to take in designing improved water distribution systems within the 200 acres or so commanded by terminal outlets from canals. While irrigation methods as applied to fields include borders, furrows and sprinklers, the vast majority of the holdings are laid out in small, nearly level checks planted randomly to row crops or bed crops. Each small check—some being only 3 feet by 4 feet—is separated by low ridges. Enough irrigation water is applied to flood the smallest area whether it is a furrow or small check following which, the water is turned to an adjacent check or furrow, and so on. In some instances the overflow from one check feeds a lower one down the slope which in turn feeds the next lower until the property boundary is reached.

While research studies on borders and furrows are being carried out in India, it might be profitable to give attention to the traditional small check methods of irrigation. These latter have considerable

potential for managing irrigation water efficiently but, the size-shape-area relationships for different soil types and irrigation stream sizes must be established. The optimum arrangement of checks within the field must be determined and limitations for an overflow from one check feeding into another needs considerable study because water needs for a given check vary with soil type and stage of crop development.

The effect of bund size on conserving and utilizing rainfall without creating waterlogging problems, should be investigated for different soil types and cropping patterns in the different agroclimatic regions. It should be specifically noted that irrigation and drainage problems are different for flooded crops such as rice than for crops grown on a dry seedbed. Also, each successive crop requires separate study, particularly when rabi (winter) crops follow rice.

The efficiency of water spreading is influenced by the degree to which field surfaces approach dead level or a plane. Thus the amount of water passing downward through various portions of land, even within the smallest irrigated unit, depends on leveling. The magnitude of seepage loss as related to degree of precision leveling of field surfaces, needs to be evaluated in order to provide sets of standards for land leveling.

Small fields restrict the kinds of land modification techniques that may be used in shaping and maintaining the desired levelness of field surfaces. Practicability and costs of doing adequate leveling with manual labor, bullock power, and machinery, need investigation. Undoubtedly, special tools and equipment adapted to India's small-plot agriculture will have to be developed.

It should be stressed that the irrigator must be free to select procedural options and that favorable physical conditions on his field are the first requirement for choices in irrigation water management. To gain acceptance for practices that can reduce water losses and make management functions easier, ways must be found to provide the cultivator with the basic information he will need to utilize irrigation water to best advantage.

Recommendations for Implementation of Research on Management of Irrigation Water on the Farm

The problems and research needs outlined in the foregoing sections suggest the earliest possible implementation of a broad and comprehensive research program in India on water use and soil management problems of irrigated lands. The program should include adaptive-type research activities in irrigated areas of river valley projects, strengthening research on irrigation and water use where essential land and laboratory facilities are available, and establishment of a central water management research center.

Adaptive-type research programs in irrigated areas of river valley projects—Interim recommendations relating to research proposals for irrigated areas of river valley projects were made by the Team on 17th March, 1967 (see Appendix 8). A summary of these recommendations along with observations gained as a result of a review and evaluation of other programs and problems in the irrigation water management field suggest the establishment of adaptive type research of water use and soil management problems at the following locations and river valley projects :

(1) At Kota (Rajasthan) at the State Irrigation Research Center, representing the Chambal River Valley Project.

(2) At Hissar (Haryana) at Punjab Agricultural University, representing the Bhakra-Nangal Project and the Rajasthan Canal Project now under construction.

(3) At Yemmigannur near Kurnool (Andhra Pradesh) at State Irrigation Research Center, representing the Tungbhandra Project.

(4) At Chakuli (P.O. Box Attabira) (Orissa) at State Irrigation Research Center, representing the Hirakud Project.

(5) At Pannagarh (West Bengal), Damodar Valley Corporation (DVC) Agricultural Research Farm representing the Damodar Valley Project.

(6) At Bikramgarh (Bihar), State Agricultural Irrigation Research

Farm or at Markham (Bihar), State Irrigation Research Center, representing the Gandak Project.

The primary objectives of this research should be (a) to determine consumptive use estimates and irrigation water requirements for important crops and cropping systems to evolve efficient irrigation practices and methods by land preparation through leveling, shaping, or other land surface modification treatments and by proper irrigation stream size in relation to slope, length and width of irrigation area, soil properties and characteristics, and crop characteristics ; and (b) to study interrelationships of irrigation with other farm practices, soil properties, nutrient requirements of crops consistent with good drainage and salt control practices for several soil-crop-climate combinations represented in these six river valley projects.

The professional staff at each of these locations should include an irrigation agronomist, soil physicist, agricultural engineer with irrigation experience, an assistant plant physiologist, assistant chemist, assistant statistician, and three to five research assistants and junior science assistants.

We want to emphasize the need for adequate planning and funding for the necessary nonprofessional type of support, together with adequate physical facilities for the professional team. Because this need is so obvious, it is often omitted from reports and plans—and unfortunately left unimplemented, severely handicapping an otherwise well planned program.

Planning and funding for such supporting elements should be spelled out. These include adequate laboratory space and equipment, irrigation system with the necessary controls and measuring facilities, farm machinery, together with people to operate and maintain this equipment. This should be funded right along with the professional staff for most effective use of the staff, and most rapid production of research information.

The Team recognizes that the Fourth Five-Year Plan limits the establishment of Research projects of this type to only three. However, we believe the need for this research is so urgent in relation to the needs

for information available and required to guide irrigation agricultural development in these six river valley project areas, that consideration should be given toward partial shifting to funds to this research from pilot projects on assessment of new cropping patterns. Recommendations for research on assessment of new cropping patterns in pilot projects of selected command areas including minor irrigation commands are discussed on pages 75 to 78 of this report.

Strengthening research on irrigation and water use where essential land and laboratory facilities are available—The Team in its review of programs and problems in India believes that strengthening research on irrigation and water use studies at locations where work of this type is underway will pay big dividends. Key scientific staff and essential land and laboratory facilities are already available at the 12 locations recommended for strengthening (The Team did not have an opportunity to visit three of the locations recommended for strengthening. However, we understand that they are centered in important problem areas not otherwise represented by those locations visited and current research programs are being hampered by lack of adequate staff, equipment, and related supporting materials and supplies).

The objective of this research would be to determine the water use and irrigation requirements of crops as influenced by methods of land preparation, methods and systems of irrigation, water application, and cropping patterns suited to the differing soils and climatic conditions.

The following 12 locations having essential land and laboratory facilities already available, are recommended for strengthening of research on irrigation and water use (methods of preparing land, methods and systems of Irrigation, and water requirement of crops).

Location —Institution(s)—Soils

1. Punjab, Ludhiana—Punjab Agricultural University, or Amritsar—State Land Reclamation, Irrigation & Power Institute, Alluvial Soils.
2. Uttar Pradesh, Pant Nagar—U.P. Agricultural University—Foothill Terai Soils, or Roorkee—State Irrigation Research Institute and Research Farm.

3. Uttar Pradesh, Kanpur—State Agricultural College—Alluvial Soils of Gangetic Plains.

4. Rajasthan, Kota—State Irrigation Research Center and ICAR Soil Conservation Research, Demonstration & Training Center—Black Deep Soils. (waterlogged saline).

5. West Bengal, Kharagpur—Indian Institute of Technology—Lateritic Soil. (Old Alluvium)

6. Bihar, Patna—State Agricultural Research Institute—Alluvial Soils of Gangetic Plains. (Saline alluvial soils).

7. Madhya Pradesh, Jabalpur—J. Nehru Agricultural University—Black medium Soils.

8. Gujarat, Anand—State Agricultural College—Coastal Alluvial Saline Soils.

9. Maharashtra, Poona—State Agricultural College—Medium Depth Black Soils.

10. Andhra Pradesh, Hyderabad—A.P. Agricultural University—Mixed Red & Black Soils.

11. Mysore, Bellary—ICAR Soil Conservation Research, Demonstration, & Training Center—Medium Depth Black Soils; or Bangalore—Mysore Agricultural University and ICAR Regional Soil Correlation Laboratory—Mixed Black & Red Soils.

12. Madras, Coimbatore—State Agricultural College, ICAR Central Sugarcane Research Institute—Mixed Black & Red Soils.

Professional Staff at each of 12 locations—Irrigation & Water Use

Class I	*Research Assistants*
Agron. (Irrigation)	Agronomy (Irrigation)
Engineer (Soil and Water)	Engineering (Soil and Water)
Soil Physicist	

Adequate support for nonprofessional staff, equipment, supplies and facilities also should be provided (See p. 58).

Establishment of a central water management research center—Although not included in the Fourth Five-Year Plan for soil and water management research, the team recommends the establishment of a Research Center at the Indian Agricultural Research Institute (IARI) to study problems of national significance in water management, conservation, and use for crop production on irrigated and rainfed lands. Emphasis in a program of this type should be directed toward attaining a better understanding of the principles involved, the unique features of the hydrologic cycle as it relates to Indian agricultural principles and practices best suited to the utilization of the water resource for agricultural purposes, water-soil-plant-climatic interrelationships, and related aspects of the water problem as it affects the economic growth of agriculture and food production in India.

The Center, if established, should serve also as a focal point for the training of people and for coordination of other water-oriented agricultural research programs in India.

WATERLOGGING, SALINITY AND ALKALINITY

Waterlogging and Drainage Needs

Some of the world's most successfully managed agricultural lands of today began as inland fresh water swamps or low lying coastal tidelands. The famed Polders of the Netherlands present an outstanding example through their fertility, that engineering plus land and water management can win and consolidate practical victories over both submergence and acute salt conditions. In all such cases of land reclaimed from submerged or submerged situations, provision for drainage has been the first obvious and unavoidable requirement.

If one attributes these kinds of successes to well-conceived projects and good management, it may be equally appropriate to view losses of good land to waterlogging and salinity as indicative of ill-designed projects or bad management.

However, even with the best management available, if irrigated areas have no provision for drainage, the eventual outcome will be

waterlogging and, in arid climates, waterlogging with salinization. Without drainage, management can stave off the day of reckoning but cannot overcome it.

The distinguishing mark of the inadequately designed irrigation project which is doomed to failure is that provisions for drainage are not incorporated into the project as part of the total system. Therefore, a proper view of complete irrigation system design is that it must completely plan for the inevitable drainage needs even if such are not required when irrigation is first begun; or, that adequate natural drainage is such that irrigation alone is sufficient to complete the total system.

Drainage needs feature prominently in considerations for increasing crop production in India for both irrigated and rainfed lands.

When land placed under irrigation begins to degenerate, cultivators are deprived of the opportunity to produce food needed by the consuming public. There are further damaging impacts upon the public interest when the water saturates subsoils to such a degree that land eventually becomes waterlogged and is forced out of cultivation entirely. At these latter stages of degeneration, such soils are not only unproductive, but they also contribute to increased flood hazards during rainy seasons because the rain runs off when it cannot percolate downward through soils already saturated with water. In emis-arid climates, irrigation-induced salinity often complicates the pattern. There are too many examples of all of these situations operating within India's irrigation agricultural complex at the present time.

Yet, in only a few instances have systems for draining salt-affected soils, been installed on cultivated lands. For example, one moderately successful open-drain system was observed near Poona, Maharashtra (Hol drainage Scheme). A second (Manjri Drainage Scheme), also near Poona, was initiated in 1930-34 and consists of a tile drain network installed in agricultural land to deliver effluent into a series of open drains leading to an outlet into the Muthra River. In each of these cases the medium depth black soils were only moderately saline but they had been waterlogged prior to installation of a drainage

system. Water table depths and salinity levels had been lowered and an economic level of crop production was being sustained.

In Himachal Pradesh, three other tile drainage systems were observed, one of 125 acres in Nagwian near Kulu, a second of 65 acres at Majthyal, and a third at the Indo-German Project at Bangrota. In all of the latter cases, soils were waterlogged in their natural state. The tile drains fed into an underground drain pipe with an outlet to a stream, and drainage had resulted in improved crops. Salinity was not a problem in any of these instances. These installations were designed without benefit of engineering investigations of conditions such as water table depth, source of water causing the waterlogging, or characteristics of soils. Spacings, depths, and other features of the systems were somewhat randomly selected. The systems were functional, although their efficiency in relation to cost is suspect.

Two of four major drainage systems were observed near Amritsar, Punjab. The area drained by each varies from 115 to 280 sq. miles. These drains are actually large conveyances channels for excess water. For example, the Kasur drain averages 12′ deep, and 120′ wide, and discharges 12,000 cusecs at peak flow. The main drain is connected by subsidary drains 4 to 10 miles apart, averaging 5′ depth, and varying in length from 5 to 10 miles. Although saline and alkaline soils devoid of crops were much in evidence in widespread areas both adjacent to and in places remote from these drains, the area had been substantially improved, primarily as a result of disposal of excess surface water with an attendent lowering of the water table and some outflow of salt. A few open finger drains had been construted in the intervening cultivated lands. No tile drainage systems had been installed. Thus, drainage effectiveness of the systems is questionable for many of the cultivated waterlogged fields of the area.

A situation similar to that described for the Amritsar District exists at the 589-acre State Government Hansi farm near Hissar, Haryana. But here the main drain under construction by the Irrigation Department is some 35 miles away. The farm is becoming waterlogged and salinity is clearly evident at the soil surface. Crop yields have steadily decreased as water tables have risen and salinity problems have increased in the 25 years since irrigation water was first applied.

Surface drainage in the flattish plains of north India has been considerably aggravated by roads, railroads, canals and distributories which cut across the country, forming barriers to normal drainage routes. An appeal is made to landscape architects together with the Department of Public Works and drainage engineers to design borrow pits into effective drainage channels running beside the raised roadways which have blocked the country's normal drainways.

A pertinent example of a need for this kind of integrated approach for help in land and water management problems was observed over many miles of road between Dehra Dun and Delhi. An unseasonable 2-inch rain had occurred in late March at wheat heading time in Uttar Pradesh and adjacent States. Many fields had been flooded, some depths of several feet, as runoff water stacked up along the side of raised roadways. It was obvious that borrow pits were aiding somewhat in increased flow of water along the roadside toward natural outfalls. However, had the borders between pits been smoothed, the flow would have been much less impeded and many fields that were suffering flood damage might have been cleared of excess water more quickly. Had there been a series of drainage channels and tanks of substantial depth (as described previously on page 32) crops would not have been so severely damaged by inundation, and critically short water would have been stored.

Certain changes in water management practices of irrigation systems presently used in India could reduce wastage, expand crop production, and protect irrigated lands from deteriorating, remembering that combined irrigation and drainage systems can be used also to reclaim and improve lands where waterlogging already limits agricultural productivity.

One begins with the premise that in this stage of India's history, the prime objective of seeking improvements in land and water management is to increase the output of food crop with the minimum of lapsed time.

Waterlogged Soils without Salinity Problems

Low lands in high rainfall belts suffer from water surplus during

monsoon. Many are so thoroughly waterlogged that rice may have to be harvested while water still remains in the fields. These situations have been observed in West Bengal near Calcutta and in Orissa near Bhubaneswar. The quality of the shallow ground water is good. In rabi, cultivators are frequently seen using counter-balanced hand lifts to irrigate small patches of vegetables on plots 2 to 4 feet higher than surrounding territory. Most of these lands have immediate potential for double cropping, provided drainage can be made effective. Here is a case for concerted research on methods to accomplish irrigation from drainage waters. The winter growing climate is excellent and the water quality is good. Moreover, starts have been made both in West Bengal and Orissa in using well water for rabi irrigation. A representative of the State Department of Agriculture in West Bengal cited one instance of a farmer having produced 4 crops. Although this is a most exceptional performance, it was done on land customarily producing but a single paddy crop per year.

Coastal Saline Soils with High Water Tables

Along the sea coast, there are many opportunities to effect land reclamation, but this type of work has barely started. The process is slow and the capital investments required are heavy. Drainage systems must be well planned, reliable and activated by low lift pumps in order to handle drainage waters with levels at or below mean sea level. The experimental research station at Canning Town, West Bengal, operated in conjunction with the Central Rice Research Institute, Cuttack, (Orissa) could be developed to study soil and drainage problems. At the moment, its main activity appears devoted to testing rice varieties for salt tolerance. The larger job of reclaiming soils enough to grow a wide variety of crop plants needs serious thought and attention.

Other possibilities for research of this type exist in Maharashtra and Gujarat.

Inland Saline-Waterlogged Soils of Irrigated Areas

Saline soils having high water tables as a result of irrigation without provision for drainage constitute a major loss of production

capacity in India. Corrective measures should be avidly pursued, particularly in the Punjab-Haryana region and south-central Uttar Pradesh where canal irrigation is of major importance to agriculture. Separate studies of the Punjab problem area were made in 1966 (Ref. 14). Also, materials relating to the history of salinity encroachments as observed by Indian agricultural scientists since the first appointment of the Reh Commission in 1876 have been assembled and embodied in this report as Appendix 9.

A rapid recovery is not expected, but certainly the advancement of waterlogging and salinization must be arrested and trends reversed for the good of India's future and for the protection of its substantial investments in irrigated agriculture.

Salinity in the soils with perched water tables represents a special case of more rapid buildup of water tables because lesser volumes of water were required to saturate the soil profile. The increasing numbers of tubewells being installed in Punjab, Haryana and Uttar Pradesh can be expected to lower water tables where there is hydrological connection between the upper water table and aquifers tapped by tubewells. But with perched water tables, the only recourse will be to install open channels or tile drainage systems. Studying drainage methods under field conditions that might provide reclamation of waterlogged-saline lands most rapidly, effectively, and economically is a most urgent research need.

Saline-alkali Soils

Saline-alkali soils represent a further degree of degradation where the amounts of sodium having entered the cation exchange complex of soils will have to be replaced chemically with calcium. These soils have become dispersed so that permeability to water has been greatly reduced, thus increasing the difficulties of reclamation even though good leaching water and adequate drainage systems are provided. Their restoration lies further into the future, and will be slower and more expensive. They probably cannot be reclaimed in time to contribute much to the immediate food emergency but they can be restored to productivity eventually. The research values in giving these soils attention now lie more in arresting such degradation in good soils.

Water Quality Problems

The Indian rainfed or snowfed rivers and streams provide good quality irrigation water with which nearly all canals, diversion systems and tanks in India are supplied. Exceptions to good quality water from streams occur near terminal ends of rivers during low water season when brackish waters intrude from the coast.

Tubewells and dug wells, on the other hand, reflect a wide variety of underground conditions ranging from good to saline. Water from these wells will require evaluation from place to place and from time to time. The same applies to drainage water used for irrigation.

The weak point involving work where composition of irrigation waters is important was found in experiments relating to seepage losses, in that engineers seemed not to be aware of the strong influences waters of various salt concentrations and composition exert on percolation rates. Of course, nearly all such experiments use the same water as that carried by the canal system whose seepage characteristics are under investigation.

We observed that State and University laboratories located in salt-influenced areas are aware of water quality relationships to crop production and that programs have been established for checking salt contents of various water sources, including boron.

Recommendations for Implementation of Research on Waterlogging, Salinity and Alkali

The problems and research needs outlined in the previous sections dictate that the real need for preventing extensive areas of waterlogged, saline, saline-sodic, or nonsaline soils from further deterioration is to establish *coordinated pilot research projects on drainage-salinity* in representative soil-crop-climatic regions of India. To this end, we recommend the establishment of a national center and three regional centers for research on the application of principles of drainage and the management of salinity and alkalinity in cultivated soils of India.

Considerable information is available in India and elsewhere on

the principles of draining waterlogged soils, how to avoid the buildup of salts, how to reclaim saline and/or alkaline soils, the tolerance of crops to various amounts and kinds of salts, irrigating crops with water of poor quality, and related aspects of managing saline and sodic soils. All too often, corrective or preventative measures are not economically feasible. However, until and unless these principles and practices are put together and evaluated on a field, farm, and catchment basis, their effectiveness or feasibility in preventing, alleviating or correcting waterlogging of productive agricultural lands will never be known. It is this type of research endeavor that is recommended in the establishment of pilot research projects on drainage-salinity at a National Center and three Regional Centers in India.

The National Center representative of India's alluvial soils is recommended for establishment in association with the Agricultural University at Hissar (Haryana). This Center should also investigate regional problems not covered by the other centers.

The three regional centers recommended are :—

(1) One representative of black soils in association with the Agricultural College and other research groups at Poona (Maharashtra) or in association with J. Nehru Agricultural University, Jabalpur, (Madhya Pradesh).

(2) One representative of the mixed red and black soils in association with Mysore Agricultural University and Southern Regional Soil Correlation Center, Bangalore or in association with Central Rice Research Institute, Cuttack (Orissa).

(3) One representative of the coastal alluvial saline soils at the Central Rice Research Institute, Cuttack (Orissa) or associated with the Eastern Regional Soil Correlation Center, Calcutta (West Bengal).

The selection of the alternative locations mentioned or others not mentioned should be based on availability of facilities and land available and representative of the drainage or drainage and salinity problems of the respective soil groupings. Although the States involved should contribute substantially to the research by supplying facili-

ties, land, and other support, it would appear that these centers should be aligned directly under ICAR since the research would be on problems of regional or national significance.

The overall objectives of the National and Regional Centers would be to study existing principles, methods and practices of draining the various kinds of soils under varying conditions of salinity, alkalinity, or salinity-alkalinity in relation to crops and cropping practice adapted to the farming patterns of the area. This would involve evaluations and assessments of soil characteristics and properties such as infiltration, hydraulic conductivity, moisture retention, density, porosity, soluble and exchangeable cations and anions, salt content, gypsum and lime status, pH and ground water level and quality as they exist before drainage systems are installed and as they change and are affected by quality and quantity of irrigation water and by the various types and designs of drains and drainage systems.

Required would be a pilot research farm of approximately 500 acres that would permit the establishment of a network of various kinds of drainage systems, connected with an appropriate outfall to achieve optimum functioning of each system. Under evaluation should be drainage materials and installation methods; depth, spacing, and type of drain (open ditch, tile, pump, etc.); and cost-benefits of each. Possibly the Hansi Farm near Hissar could serve as one such pilot research farm. Installation cost of drainage systems of the types needed to get answers to the problem is estimated at Rs. 1000/ per acre. Funds to offset the initial installation cost might be elicited from outside sources.

The effectiveness and cost of reclaiming salt-affected soils by employing leaching, chemicals, organic materials, and other amendments need to be explored. Methods of planting and irrigating different crops should receive study in terms of effects on germination of seed, plant growth, and distribution of salts in the soil.

A laboratory would be essential at the National Center and at each of the Regional Centers, primarily for the purpose of evaluating chemical, physical, and other changes that occur in soils, plants, and waters associated with drainage, irrigation, amendment, and other

variables. Modern equipment and instrumentation are required to evaluate the what, why and how of changes in soil, plant and water properties occurring as a result of experimental variables imposed.

Appendix 10 gives additional information as to proposed locations and staffing of scientists for the three Regional Centers.

Also recommended as an integral phase of the program at the National Center would be field plot and greenhouse studies of the salt and alkali tolerance of crops and crop varieties, particularly for crops indigenous to India. Tolerance of crops as reported from outside India should be verified as to conditions of soil and climate in India. The quality of irrigation and ground water as it affects plant growth under India's varying conditions of soil and climate needs study and evaluation. The reportedly high bicarbonate content in waters needs research to find out its effect on plant growth and soil characteristics. Methods of using poor quality irrigation water need evaluation in relation to precipitation patterns, soils, crops and cropping practices and other conditions.

Drainage requirements of crops as augmented by soils and salts should be explored with a view toward using the best cropping practice possible until waterlogging and salts are reduced to tolerable levels or removed.

The scientific staff at the National Center should include people trained in drainage engineering, irrigation engineering, soil chemistry, soil physics, soil management, plant chemistry, plant physiology, agronomy, and statistics.

Adequate support for nonprofessional staff, equipment, supplies, and facilities also should be provided (see p.58),

The National Center should also serve as a training center for students and junior scientists interested in or engaged in drainage, salinity or alkalinity research, technical assistance, or teaching endeavors. Hopefully, the Agricultural University, Hissar (Haryana) would expand its academic program to include advanced courses in this field and become a center of excellence for graduate study in the field of drainage, soil-salinity and alkalinity for India.

The Research Consultant Team believes that fundamental research on determining new or evolving adaptions of existing principles in soil-water-plant-climatic relations for varying saline or saline-alkali soils is also a great need for India in the years ahead.

To help upgrade research and other programs dealing with saline soil problems, an *Indian scientist* having a depth knowledge of methodology, equipment, and principles and practices for managing salt-affected soils should be located in States other than those selected for the Centers and where this problem is acute. In some instances, a scientist having this type of training and experience is already on the staff, but his research interests and assignment are not solely with soil salinity. In any case, scientists, if so selected and assigned, should maintain close liaison with both the National and Regional Centers in terms of exchange of technical information, keeping abreast of latest methodology and technology, and coordinating his research effort with those of others.

To accomplish this objective, a soil chemist, an agricultural Engineer and 4 research assistants (if not currently on the staff) should be employed at each of the following locations: Amritsar (Punjab), Jabalpur (Madhya Pradesh)*, Kota (Rajasthan), Patna (Bihar), Kanpur (Uttar Pradesh), Anand (Gujarat), Hyderabad (Andhra Pradesh)*, and Calcutta (West Bengal)*.

SOIL, CROP & CLIMATIC INFLUENCES ON IRRIGATION AGRICULTURE

Soils and Soil Management Practices for Crop Production

The team in its objective of evaluating research on water use and soil management practices had only limited opportunity to evaluate specific soils and soil problems in relation to food production potentials in India. Even so, it is clearly evident from our reviews that India's soils require a better understanding. The report by Kellogg (Ref. 11) on soil survey and soil conservation in India comprehensively summarizes the subject. Field experiments on any biological pheno-

*If alternative locations are chosen for regional drainage-salinity centers, then Poona (Maharashtra) and Bangalore (Mysore), would be suggested locations for the "State" soil chemist on soil salinity.

menon must be tied to the soil involved and soils must be identified, characterized, classified, and correlated with other soils throughout India. A real need here is to adopt a system of classification at the national level that takes account of other world-wide systems. We found little attention directed toward detailed surveys of soils occurring on experiment stations. We recommend most strongly that before experiments are undertaken, experimental sites in India be surveyed and characterized as to the soils involved. It doesn't suffice to identify a soil as "black", "mixed-red-black", "alluvial plains", "alluvial coastal plain". Such very general descriptive terms do not adequately portray the soil properties that may be involved in responses to management. In the case of black soils, descriptions are further broken down into light, medium, and heavy but these terms refer to depth and not to texture or other inherent soil characteristics.

Most of India's agricultural soils are severely compacted and often crusted. After 4 to 5 months of drought, water penetration is quite restricted. For example, an unseasonable 2 inch rain had occurred in late March at wheat heading time in the plains of Uttar Pradesh and adjacent States. It was observed that many fields had been flooded, some to depths of several feet, as runoff water stacked up along the side of roadways. Ordinarily, the team would have expected the soils in question to be much more receptive to water, since no rain had occurred over a 5-month period.

The number of repeated tillage operations performed for a single cropping period in India has been difficult to understand; yet, when one considers the low-level power inputs involved in each tillage operation, the system takes on more meaning. As many as 10 tillages for seedbed preparation for wheat and 5 to 8 for rice were reported at one or two locations as desirable for good "root-bed" or "seed-bed" preparation. From review and observation of some operations in progress, depths of the initial tillage to about 8 inches are attempted with subsequent operations being about 4 inches or less. But, it is doubtful that 8-inch depths are actually achieved very often. With this high intensity of shallow tillage over centuries, the shallow plow-soles observed must exist extensively—in association with Indian bullock-powered tillage practices. The Team did not have opportunity

to examine many different types of soils for these particular characteristics on a widespread area. However, we did have adequate opportunity to observe the results of repeated trampling by India's estimated 700 million animals which graze lands as soon as crops are harvested. Soil compaction resulting from intensive grazing and tillage of the land and the effect this has on responsiveness of soils to management practices need critical evaluation, particularly in relation to the expanding interest in high-yielding cereal crops for the rabi season.

The Team was surprised at the shallow rooting depth of crops, as observed to be the case and as reported by Indian scientists. In a few cases, an 18-inch rooting depth was cited, but most crops were reported to have had only a 12-inch rooting capability. We suggest the desirability of securing research evaluations of soil properties and other factors which are now unfavorably affecting root penetration.

Reasons were advanced in response to questions raised in many parts of the country about puddling rice fields. They included water levelling of the field, reduction of seepage losses, weed control, providing a more desirable transplanting medium and maintaining low redox potentials in root zones for rice. In only one instance did we find an experimental effort directed toward evaluating the effects of puddling on losses of water by seepage beyond the rooting zone.

Although not included in any of the responses, it appears to the Team that the limited power available for tillage and the necessity of working the land during the monsoon weather are perhaps the fundamental reasons for puddling. In other words, for circumstances prevailing when the land has to be cultivated, puddling is the unavoidable consequence. Fortunately, the rice plant is adapted to these conditions. Puddling soil destroys structure, at least temporarily. Yet, in a pattern of two or three crops per year which India should strive toward, other crops requiring aerated root zones would be grown following rice. How can soils be manipulated to meet the changing demands for these cropping patterns ? There is a wide scope for soils studies on practices such as puddling and number and type of tillage needed in order to separate fact from myth and tradition.

Approximately two-thirds of the rice acreage in India is on rain-

fed land and here soils are either puddled for transplanting of the crop or they are tilled and seeded prior to monsoon. Evaluations of these and associated practices as to effects on changes in soil characteristics and productivity need much study.

The advantages to be gained from levelling land have been discussed elsewhere in this report. However, from a soil fertility standpoint, the team cautions against a viewpoint that levelling or shaping of land surfaces is the final solution to getting more food solely through applying water to leveled land. Often, the fertilizers needed to make the out areas productive cost more than the land levelling operation.

The extensive black clay soils of India present special management problems in that they crack while dry, seal over where wet, and can be tilled only at a narrow range of moisture tensions. As discussed, waterlogging is a major problem of these soils both under irrigated and rainfed agriculture. Improved management practices are needed for these soils if sustained or increased production of crops is to be realized.

Agricultural goals for India, which distinctly appear within the realm of potential achievement because of India's favorable year around growing climate, can be to make two crops grow where one grew before, and to make three crops grow where two grew before. Many millions of acres of good land are lying fallow during rabi. These could be carrying crops, except that water is not available. Since it is water rather than land which is in short supply during rabi, strong emphasis has been placed on saving water which presently is wasted. Land shaping, irrigating to fit crop needs, minimizing seepage losses, and gearing water charges to amounts of water used are clearly the directions to take in the dual interests of raising cropping efficiency and expanding irrigation to more land, particularly during rabi. Exploitation of underground water resources is a further means for bringing more acres under cultivation during the dry season.

On rainfed lands not in reach of irrigation systems, crop selection can lead to greater use of soil moisture. Thus, deep-rooted rather than shallow rooted plants must be sought. Tillage methods must

be directed toward creating deeper zones penetrable by moisture and by roots. Land shaping can improve moisture distribution. Tillage methods, check and bund construction can be studied and designed toward improving water penetration into soils during the rainy season. Tillage operations associated with preparation of seedbeds and with weed control are certainly in need of reevaluation.

Recommendations for Implementation of Research on Soils and Integration of Practices

The Team's recommendations for research on problems in this area fall into the two categories of basic soil properties and characteristics in relation to soil and water management practices, and integration of improved crop, soil, fertilizer, and other practices into systems that tend to maximize water use efficiency toward the production of greater quantities of high quality food.

Basic soil properties and characteristics—The primary objective of this research would be to determine and characterize the physical, chemical, and biological properties of major groups of Indian soils as related to productivity indices of water, crop, soil and other management practices best suited to each soil group for economical crop production. Significant knowledge of Indian soils will have to be gained as to levels and balance of essential plant nutrients; as to aggregation, compaction, water infiltration, surface crusting, erosiveness, and other physical properties; and as to activities of organic materials and micro-organisms, if the low yields of crops in India are to be corrected by informed management. This research should seek the causes for soil deteriorations which have taken place and devise corrective measures for improving the productive potential of the agriculturally important groups of soils in India.

Research programs on basic soil properties, characteristics, and problems (chemical, physical, biological) in relation to soil and water management practices and production of crops should be initiated at the following four Centers :

1. WEST BENGAL, Calcutta—Eastern Regional Soil Correlation Center or Orissa University of Agriculturel and Technology, Bhubaneswar (Coastal alluvial soils).

2. MYSORE, Bangalore—Southern Regional Soil Correlation Center or Mysore Agricultural University (Mixed Red-Black Soils).

3. MAHARASHTRA, Nagpur—Western Regional Soil Correlation Center or J. Nehru Agricultural University, Jabalpur, Madhya Pradesh (Black soils).

4. NEW DELHI—Indian Agricultural Institute & Northern Regional Soil Correlation Center or Punjab Agricultural University, Hissar (Alluvial soils).

The Professional staff at each of four locations might include the following ranks and disciplines :

Class I	*Research Assistants*	*Research Fellows*
Soil Physicist	1 Asst. (Soil Physics)	1 Soil Physics
Soil Chemist	1 Asst. (Soil Chemist)	1 Soil Chemistry
Pedologist	1 Asst. (Soil Microbiologist)	1 Microbiology
	1 Asst. (Soil Minerology)	1 Minerology
	2 Asst. Pedologists	2 Pedology

Adequate support for nonprofessional staff, equipment, supplies and facilities also should be provided (See p. 58).

Integration of improved crop, soil, fertilizers, and other practices into systems for improved water-use efficiency and high yields of food crops would be the overall objective of this research proposal. It would include an assessment of the combined effects of variable inputs of fertilizer, plant populations, levels of irrigation, and intensity of cropping with a view toward determining the most economical and feasible combination of factors for producing food in several important farming regions in India. In some regions, the experimental variables might include two cropping sequences or two crops as compared with three or four crops per year each at two water levels ; in others, times and rates of seeding, fertilizer rates, and irrigation levels; and in still others (where the irrigation water supply is reliable), plant populations, fertilizer rates, and the introduction of promising new

crops. Thr high-yielding crop varieties, adequate weed and pest control, proper and timely tillage, adequate drainage and salinity control, and other good management features should be used in all experiments. Acceptable experimental design and ownership or control of land would be required to insure that experimental variables were adequately controlled. Results should be evaluated as to performance of a given practice at each level of input in relation to combinations of other practices. The best combination of practices in terms of quantity and quality of marketable product, high water-use efficiency, and full utilization of land on a year around basis in relation to the costs involved would be the principal goals of this research. Gross evaluations could be made of costs and benefits from the various levels of "inputs" required for any given practice and the various combinations of practices.

We recommend that experiments on the integration of improved practices be initiated in the following river valley projects and tubewell command areas.

Site No.	State	Location	Irrigation Project
		River Valley Projects	
1.	Andhra Pradesh	One of the State Stations	Nagarjunasagar
2.	Bihar	Location to be fixed	Kosi
3.	Gujarat	Headquarters at Anand or Kakrapara	Mahi
4.	Madras	Headquarters at Coimbatore	Lower Bhavani
5.	Maharashtra	Location to be fixed	Girna or Purna
6.	Uttar Pradesh*	Headquarters at Kanpur or Jhansi	Matatila dam
		Minor Irrigation Projects (Tubewells)	
7.	Madhya Pradesh	Headquarters at Jabalpur	Hoshangabad
8.	Uttar Pradesh*	Headquarters at Delhi	Meerut District or Bulandshahr
		or	
	Bihar	Patna	Patna District
9.	Uttar Pradesh	Pant Nagar	Terai Shallow District

*Alternative locations for research in Uttar Pradesh

The professional staff recommended for the program which should be conducted over a period of at least 5 years, is as follows :

(1) At each of eight field locations :

Class I	Research Assistants
1 Irrigation Agronomist & Officer In Charge	4 Agronomy
1 Soil Chemist	3 Soil Science
1 Irrigation Engineer	3 Engineering
	1 Farm Economics

(2) At the center (Delhi)—coordinating and providing technical assistance, guidance and help in summarization and analysis of data for the programs at each of eight locations.

Chief Project Officer	Class I (Senior)
Irrigation Agronomist	1 Agricultural Engineer
	1 Soil Chemist
	1 Farm Economist
	1 Statistician

Adequate support for nonprofessional staff, equipment, supplies, and facilities also should be provided (See page 58).

SOIL & WATER MANAGEMENT OF RAINFED LANDS

Bunding, Terracing, and Other Land Surface Modifications

Bunding, terracing, and analagous land surface modifications are the principal Indian soil and water conservation measures practiced in each of the major soil-slope-climatic groupings. If better ways and means can be evolved for conserving soil moisture through reduction of runoff and increasing infiltration during the monsoon, higher yields and fewer crop failures should be the reward. But it is recognized that the amount of available water that can be stored in the soil profile is finite and amounts to approximately 2 inches per foot of depth. This amount of water is generally inadequate for the production of a complete crop and requires repeated replenishing either from precipitation or from stored irrigation water. Special difficulties presented by the

heavy monsoon rains followed by a long, warm dry season are well known and hardly need elaboration. However, complete evaluation of the soil moisture and soil fertility changes produced by land modification treatments are certainly in order. For example, it would be of great interest to have measurements made in sufficient detail and depth, across transects extending at least from one ridge of one terrace or bund to that of another, from which real quantitative ideas of moisture conservation effectiveness might be obtained.

Although land shaping intended to increase soil moisture storage gives the general expectation of increased yields, such is not always the case because crop yields are affected by many interrelated factors and moisture in the soil profile is only one of these. Therefore, crop yields are not always the best criteria for research evaluation of the performance of surface modification of sloping land. However, step by step analyses of total benefits of land surface modification can be accomplished.

Since it is to be construed that the primary function of bunding and terracing is to increase the amount of moisture added to the soil and thus improve its crop producing ability over land not so treated, the associated factors brought into play must receive appropriate attention with respect to plant growth influences. Thus, the infiltration rates on both the cut and fill areas need to be determined and evaluated along with fertility levels of the corresponding areas. Conventional methods of removing top soil from one level and depositing it as fill on top of existing soil at another level have simplicity and economy in construction. However, it may be desirable to develop alternative construction methods if the exposed unproductive sub-soils are not receptive to water, or for other reasons produce yield depressions not compensated for by extra growth increases on the filled areas.

It is quite possible that infiltration on naturally steep land can be increased considerably by reshaping, regrading and otherwise altering the soil surface. The soil has an opportunity to absorb water only during times water is being supplied continuously to the surface, as during a rain or when exposure time is extended as on a leveled field

enclosed with a bund. If crop plant tolerances to inundation can be improved by selection and plant breeding, longer detention of the water behind obstructions such as bunds or terraces would be allowed with greater infiltration opportunity and resultant additions of water to the total groundwater supply.

In view of the fact that rainfed land have infiltration opportunities generally limited closely to the periods of actual precipitation, cutting and filling as practiced in land forming operations need research attention and valid measurements of benefit or lack of benefit being derived from traditional bunding operations.

Terracing, bunding and vegetated outlets help to keep erodable soil on the cultivator's land and reduce silting menace to water works and streams, primarily by modifying the runoff-flow conditions and characteristics. Therefore silt and sediment control must be considered as part of the total benefit when making quantitative determinations of the results from land development practices aimed at improving water catchment. Data applying to all of these factors are sorely needed.

Disposal of Excess Surface Water

Heavy rains in certain months of the year make surface drainage a prime requirement on both rainfed and irrigated lands. In addition to surface drainage, sub-surface drainage should be studied where waterlogging would otherwise occur.

Timely disposal of surface precipitative water from rice lands especially near the end of the monsoon season is necessary to permit the growing of rabi crops. In view of the large amount of rice that is grown without irrigation, this facet of water disposal deserves greater attention. The large acreage involved (two-thirds of the acreage of rice in India) and the benefits that can accrue if methods are developed which will stimulate the growing of rabi crops in areas where excessive wetness does not permit it now, can have a pronounced effect on food production.

Terracing of rainfed lands is almost universal throughout India

A practice applied so extensively deserves greater and more intensive research attention than it is receiving. The multitudinous variations in climate, soil, and topography combined with the existing patterns of land ownership and farming provide opportunities for improvement in design, construction, and maintenance of such works.

The emphasis on reducing the silt load of streams justifies increased study of the role that the various conveyance channels play in conducting excess water from the cultivated land to the larger streams. These are said to contribute greatly to the total sedimentation problem. The roles of grade, shape, surface condition and vegetation and crop residues of terraces, outlets and field channels on decreasing the silt load of the runoff waters should be investigated. The benefit will accrue not only to the cultivated land but to downstream installations and populations.

Tanks, underground recharge areas, and similar facilities for detaining water on the surface are excellent devices for reducing peak stream flows and providing ways for more desirable use of this resource. Since rain often falls at a rate greater than the ability of land to absorb it, the excess will either appear as runoff, too often to swell an already high flow, or it may be conveyed to a storage area for a more productive use at a more opportune time.

Since all water originates as precipitation, society as a whole has a vested interest in its control for the maximum benefit to all. This includes not only the irrigation farmer and the cultivator of rainfed lands but also the city dweller who depends on water for available food and electric power. Additionally, excessive runoff from rainfed land contributes to flood hazards and the various related ramifications.

It seems desirable to increase the awareness of not only the cultivator but the city deweller as well that each has a stake in the orderly development and control of India's water resources and that this development and control logically begins at the point of origin—the rainfed lands.

Watersheds

Most of the water used in agriculture and in power development

has its source in rainfed watersheds. The yield of water, the low peak flows of streams, and to a large extent the sediment load are determined by the type of soil and water management found on the watershed. The importance of watershed areas as a primary source of water production justifies considerable emphasis on watershed research. This research effort will range from learning how to measure and describe the water yield characteristics of different watersheds as they are affected by different variables, to developing improved methodology and techniques for measuring such changes more accurately and more economically and ultimately to control or modify watershed function. The current effort in this direction is much too meager considering the magnitude and importance of the water resources involved.

The complete hydrology of a watershed involves many disciplines including engineering, geology, meteorology, forestry, agriculture and others. It often encompasses land whose agricultural value is considerably less than that of the land which it supplies with water. It often involves sociological problems as well. The technology and methodology for research under the severe conditions of grazing experienced in India will require special development. Though many excellent research procedures are being followed in other countries, many of these need considerable modification to be useful in India. This merely makes the problem more urgent since methodology must be developed before watershed characteristics and treatments can be researched and sound data leading to indisputable conclusions obtained.

There is considerable opportunity for inter-ministerial and inter-departmental effort in such a program which involves large land areas and many facets of human activities. The broad implications and effects of such treatments as reforestation and grazing control are generally known, but specific quantitative evaluation of management changes on runoff and erosion are urgently needed.

In view of the large area and the extensive nature of most watersheds, it appears desirable that parallel studies be conducted on small plots for more precise measurement of response to treatment. Such parallel studies seem desirable in view of the often "unexplainable"

behavior of some watersheds visited. In one case, during the early part of the year the cultivated watershed produced more and quicker runoff than the companion forest watershed. But as the growing season advanced, the runoff from the cultivated land approached that of the forested watershed. It was suggested as a possible explanation that the character of forested watershed remains essentially unchanged throughout the year whereas the cultivated watershed experiences a gradual increase of vegetative cover as the growing season advances. It is expected that more detailed studies on small plots would shed considerable light on similar unexplained data.

The utilization of artificial rain equipment is rapidly becoming a valuable tool in soil and water research. It permits the design of specific experiments at the will and convenience of the researcher. It permits the use of specific reproducible characteristics of intensity, duration, amounts and occurrence in the research effort. This places the research at the will of the experimentor in lieu of total dependency on the vagaries of the weather.

Watershed hydrology information is transferrable to other region only to the extent that the conditions at both sites are completely described. Complete descriptions of precipitation are required. Suitable descriptions of the soils and vegetative covers are equally important. Soil description is a basic component of evaluations. Methods for describing hydrologic characteristics of soils are not entirely satisfactory, but effort in this direction is worthy of consideration.

The infiltration characteristics of major soils, i.e., benchmark soils, in India should be oblained. Various methods have been used for this purpose, ranging from ring infiltrometers to artificial rainfall applicators. The type of characterization done in 1954 and continued intermittently since then by the Watershed Hydrology Section of the U.S. Department of Agriculture has much merit. Four groupings of soils were found quite helpful and adequate in delineating broad hydrological influences. This simplified soil grouping into A, B, C, and D soil groups has been very useful in understanding and predicting the behavior of watersheds.

The method employed by the Research Division of the Soil Con-

servation Service in 1937-39 is reported by *Musgrave*. Ring infiltrometer and artificial rain applicator tests carried out by two mobile units, using the identical technique, made it possible to array the major soil groups throughout the U.S. in order of their infiltration capacities.

Control of Soil Erosion by Water

Terracing, bunding and other similar land modification practices are acknowledged the world over as an effective means for controlling surface runoff and reducing erosion. Only minor changes in such practices have been made in recent years, and these were made very slowly. In view of the magnitude of the terracing and bunding programs in India, it is desirable that a research effort commensurate with the construction program be inaugurated to obtain quantitative measurements on methods, size and shape, spacings, depths of cut and fill and their relations to erosion and hydrology.

For Indian field situations, it would be highly desirable to obtain complete hydraulic and erosion characterizations of changes that occur when fields are bunded or terraced. Indisputable evidence on the benefits of land modification practices under Indian conditions would do much to stimulate support for sound soil erosion control programs.

Though terraces and bunds are acknowledged erosion control devices, more thorough evaluation of the precise role which these structures play in the erosion picture and measures of their effectiveness is needed not only in India but many other countries. Unfortunately, too many research efforts in this direction have been limited almost exclusively to measuring the erosion passing through terrace outlets. This is only a small part of the total erosion picture. It merely shows how much soil is leaving the terraced area, and indicates almost nothing of what is occurring on the field above the terrace or in the terrace channel.

Evaluation and explanation of the erosion phenomenon on steep land and on terraced land are very complex. Research facilities will require a large expenditure for the field installation as will execu-

tion of the program. Success is of course predicated on a capable, well-equipped staff with adequate supporting resources.

Erosion control is complete when the precipitation is all absorbed, or the surface runoff is reduced to a noneroding rate. Ideally this is best accomplished by holding every drop of rain where it falls. The runoff and erosion control capability of bunding and terracing can be reinforced considerably by using certain tillage and cropping practices and improved crop residue management. In the U.S. and some other countries these practices form a basic part of the runoff and water erosion control alone and in conjunction with other practices.

Considerable research is needed to develop similar practices adapted to India's wide range of agro-climatic conditions. This research must be an adaptive field-type effort with necessary consideration given to the fluctuations in rainfall, the heavy demand for crop residues as animal fodder, and other considerations indigenous to Indian agriculture.

In view of the importance of water and in the interest of soil conservation, an intensified research program that includes tillage and crop residue management is highly recommended. The effects of crop residues in reducing loss of soil moisture, especially from the top 2 to 3 inches, have a profound influence on the success or failure of new seedings.

Ravines and gullies are spectacular evidences of advanced erosion. In view of the severity of such erosion, radical rehabilitation measures are generally required. Since most of the areas damaged by ravines and gullies have lost much of their value as conventional farmland it is imperative that alternate uses for such land be developed. Preferably such uses must arrest advancing gullies or ravines, heal the surface scars, and at the same time provide some economic return. The Consultant Team was favorably impressed by some excellent examples of ravine control in Rajasthan (Kota) and land slip control in Uttar Pradesh and Himachal.

The research problem involved in ravine control is complicated by many ramifications, including diversion of surface water, grazing

prevention or control, reforestation, reseeding with desirable grasses, and growing certain trees or shrubs which may have economic potential. In view of the damage that ravines can cause if they are not controlled and in view of the scarcity of land, greater support for research in this area appears justified.

Control of Soil Erosion by Wind

Wind erosion is a major problem in the drier and sandier regions of India. The long periods of hot, dry weather combined with the pulverizing effect of animal hoofs on sandy soil create a favorable condition for erosion by wind. The problem is further aggravated by the almost complete utilization of crop residues for animal feed. After crop harvest, most lands are intensively over-grazed.

Much research has been done in India and in other countries on the underlying principles of wind erosion. Many of these principles have universal application, but require more precise evaluation and adaptation under the climatic and soil conditions of India. The Central Arid Zone Research Institute has been a leader in this work in India, and its work should be intensified.

Fortunately, many of the basic principles can be extrapolated to or from other countries with only minor modification. The work of such institutions, as the Central Arid Zone Research Institute, should be sufficiently financed to permit an expanded effort in adaptive research and demonstrations. A pilot research demonstration project in a wind erosion hazard area should be established for field testing of the best protective measures now known. This would permit evaluation of such practices and measures under India's conditions. It is felt that this type of evaluation, with such adjustments in current recommendations as may be necessary, will do much to advance the state of knowledge of wind erosion control and increase its acceptance.

The effect of different windbreaks has been studied by many. In general it may be concluded that the best windbreak may be one equivalent to an "orchard of fenceposts" spaced about 10 feet in all directions. The most desirable windbreak is one that merely slows the wind to a nonerodible velocity.

Work on developing or finding vegetation that will bind and tie down moving sand dunes and stabilize other wind erodible soils should be encouraged. Vegetation that is unpalatable to livestock, yet which may have an economic value, is most desirable for this purpose.

In some countries wind erosion is a hazard on irrigated lands as well as rainfed lands. Such should not be a major hazard in India, primarily because the small landholdings with the resulting roughness and character of the land surface produced by channels, ditches, and land boundaries form natural barriers to high velocity winds. The basic principles of wind erosion control are applicable to both irrigated lands and to rainfed lands. Some adjustment must be made for two such widely varried conditions, but these are generally minor. The major immediate problem would be that of field testing and demonstrating the accepted practices.

Recommendations for Research on Soil & Water Management Problems of Rainfed Lands

First priority attention of the Team, as outlined, has been directed toward irrigated agriculture's research problems and needs toward bolstering food production in the immediate years ahead. It was not possible in the limited time available to meet many of the scientists and see and review much of the experimental work underway in rainfed areas. However, since approximately 360 million acres (probably 70 per cent) of the cultivated lands in India depend upon natural precipitation, much of which falls in the monsoon season (June-September), the importance of the rainfed areas to India's food base for many years ahead is self-evident.

An assessment of the resource problems and research needs of rainfed lands enumerated previously, strongly dictates a reorientation of existing and a substantial strengthening of future research activities at the Soil Conservation Research, Demonstration, and Training Centers throughout India. Research emphasis should be on the management of water—its infiltration, storage and drainage from soils and safe disposal of excessive amounts from lands having widely varying soil characteristics and slopes.

The several difficult and complex soil and water management problems as enumerated were observed throughout India as being acute and adversely affecting the food production potentialities of these resources. We recommend, therefore, that funds for a greatly accelerated research effort be allocated to locations representative of the major soil-climate-type of farming regions of India. The following problem areas are listed, recognizing that the Team did not have the opportunity to study on-going research activities in soil & water conservation :

1. Gray and Brown soils, arid to semiarid zone, less than 25″ annual precipitation. (Parts of Rajasthan and Haryana). The Central Arid Zone Research Institute, Jodhpur (Rajasthan) is representative of this problem area.

2. Soil Conservation Research Demonstration and Training Center Kota, where the overall objective is of stabilizing gullies and arresting their advancement into ravines of black soil alluvium is recommended for continuance. To provide better liaison with other research groups, consideration should be given to consolidating all Center & State sponsored research activities in the Kota area at one location.

3. Medium & shallow black soils of central India, medium annual rainfall of 40 to 50″ (Madhya Pradesh and Northeastern portions of Maharashtra). The establishment of Soil & Water Conservation Research Center for rainfed land for this vast area is recommended, either at Nagpur, Maharashtra, in association with the GOI Soil Correlation Laboratory, or at Jabalpur, Madhya Pradesh, associated with Jawaharlal Nehru Agricultural University.

4. Medium to shallow black soils of southern India, low to medium rainfall belt (25″ annually). The Soil Conservation Research, Demonstration and Training Center at Bellary, Mysore State, is representative of this problem area and work at the center should be strengthened.

5. Ferruginous red soils, medium precipitation area of 35 to 45″

annually (Andhra Pradesh, Madras, Mysore & Orissa States) Ibrahimpatan, A.P.

6. Undulating to steep hilly lands of south India, elevations upto 2500′, acid lateritic red soils, yearly precipitation of 50″ with approximately 90% received during the period April-November. The Soil Conservation Research & Training Center, Ootacamund (Madras) is located in this problem area.

7. The Soil Conservation Research, Demonstration & Training Center, Dehra Dun (Uttar Pradesh) conducts research on methods for control of soil erosion by water, land slide stabilization, reclamation of chos (seasonal stream), and collection of data on rainfall-runoff relations as affected by various land use treatments. The Center represents parts of the northwestern Himalayan region and receives about 65-70″ of precipitation annually, a major part of which is received during the monsoon months of June to September. Soils are sandy loam to clay loam in texture and slightly acidic to neutral in reaction (pH 6.4—7.0) and occur on moderate to extremely steep slopes. Research on water and soil conservation problems should be extended to the Chakrata Hills areas to the north of Dehra Dun.

8. Mountain and hilly land soils receiving high rainfall on slopes of over 100 per cent (Himachal Pradesh, Northwestern Uttar Pradesh). There is no center-supported research activity to work on these problems in Himachal Pradesh, yet these highly erosive soils on exceedingly steep slopes associated with the high rainfall of the region present some of the most complex problems of managing these resources anywhere in India. Consideration should be given to the establishment of a station for this area. This Center should also deal with all problems pertaining to Kuhls and Kuhl irrigation systems.

9. No recommendation is made on Soil Conservation Research, Demonstration & Training Centers at Vasad (Gujarat),

Hazaribag (Bihar), Chatra (Nepal), Agra (Uttar Pradesh), or Chandigarh (Punjab).

The Team is aware that considerable research has been conducted in Soil & Water Management practices for rainfed lands in the various regions, but with few exceptions these findings have not been summarized and evaluated. To this end, we recommend that a technical committee of Indian Scientists make this assessment, publish the results, following which more detailed suggestions can be formulated as to the direction and orientation of needed soil and water conservation research expansion for rainfed lands in India.

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APPENDIX 1

Itinerary of Water Use and Soil Management Research Consultant Team (See also attached map showing tour routes)

January 16th, 1967	Arrival New Delhi—Chester E. Evans, Irrigation Agronomist and Team Leader, Agr. Research Service, U.S. Department of Agriculture, Fort Collins, Colorado; Perry R. Stout, Professor of Soil Science, University of California, Davis; and Stephen J. Mech, Irrigation and Drainage Engineer, Agr. Research Service, U.S. Department of Agriculture, Prosser, Washington. Met at Airport by John T. Phelan, USAID-SCS/PASA, New Delhi. Afternoon checked in at USAID Mission.
January 17th	Administrative details. Briefings on Indian reports, evaluation of papers, maps, and plans provided by USAID and GOI. Briefing by Deputy Director, Russell Olson, Chief, Agriculture Division, Oliver Bauman, Deputy Chief, Agriculture Division, John T. Phelan, Chief, Soil & Water Use Branch.
January 18th	11 A.M. — Meeting with C. Subramaniam, Minister, Food and Agriculture. 2.30 P.M. Meeting — Dr. Guy Baird, Director, Indian Agricultural Program, Rockefeller Foundation.
January 19th	Visited Indian Agricultural Research Institute.

	Met Director, Heads of Agronomy & Agricultural Engineering Divisions and Irrigation Section.
January 20th	Visited Soil Science and Agricultural Physics Divisions of I.A.R.I.
January 21st	Discussions on research work, plans, and charge of team by Deputy Director General and Deputy Agr. Commissioner, Indian Council of Agricultural Research, G. Baird of Rockefeller Foundation, John T. Phelan & James Coover of USAID-SCS/PASA, Indian counterparts, and Team members in attendence.
	Discussion with Director General, I.C.A.R.—Dr. B.P. Pal.
January 22nd	Sunday
January 23rd to 25th :	State of Punjab
January 23rd	New Delhi to Amritsar by Air—Met by Executive Engineer, Land Reclamation Irrrigation and Power Research Institute. Meeting with Director and his staff. Went to various sections of the Institute. Afternoon to Malikpur and return. Visited Kasur Drain and Hydraulic Field Station, Malikpur.
January 24th	Visited Do Burj's Research Station
	Departed for Ludhiana by road—met by Dean, Agricultural Engineering Punjab Agricultural University, and Byron Bondurant, Ohio State University—USAID, and held discussions with Engineering Staff.
January 25th A.M.	Visited Drainage, irrigation and soil and water management research at the University farm and Soil Science Laboratories.

	P.M.	Departed for New Delhi by road
January 26th		Republic Day
January 27th		Second meeting with Deputy Director General, ICAR who discussed the research work and assignment of the Team.
		Ellis Hatt of Ford Foundation, C.R. Pomeroy of Rockefeller Foundation, John T. Phelan, James R. Coover and U.S. Madan of USAID and ICAR Counterparts were at the meeting.
January 28th & 29th		Saturday & Sunday.
January 30th		New Delhi to Bhubaneswar via Calcutta by Air. Met by Joint Director, Agriculture.
		Attended East Zonal Workshop on Soil Science at Central Rice Research Institute and met the delegates. Returned in evening to Bhubaneswar.
January 31st		Bhubaneswar to Cuttack and return by road. Attended East Zonal Workshop on Soil Science and visited different sections and farm of C.R.R.I., Cuttack.
February 1st	A.M.	Bhubaneswar to Konarik and return. Visited the tubewells, potato cultivation, hybrid wheat plots, drainage, delta and delta canals, sea coastal plantations and sand dune stabilization work.
	P.M.	Meeting with Vice Chancellor, Orissa University of Agriculture and Technology and his staff and visited Research farm of the University. Met J.W. McKinsey, Leader of University of Missouri-USAID Team.
February 2nd		Left Bhubaneswar for Sambalpur by road. En-route met by Asstt. Engineer and District

		Agriculture Officer, at Angul and discussed Darjang Irrigation Project.
February 3rd		Visited Irrigation Research Center, Chakoli (Attibira) and Indo-Japanese Farm, Irrigation Canals at Bhursepalli, Bananna Culture at the Horticultural soil conservation and General Farm at Gambharipalli.
February 4th	A.M.	Had discussion with Superintending Engineer regarding Canal water supply and distribution and visited Hirakud Dam and Hirakud Research Station.
	P.M.	Left Sambalpur by rail for Kharagpur.
February 5th	A.M.	Arrived Kharagpur. Met by Prof. A.C. Pandya, Head of the Agriculture Engineering Department of I.I.T., Kharagpur.
February 6th	A.M.	Visited Research Farm of the Institute, Department of Agricultural Engineering, Civil Engineering, Hydraulic Laboratory and Central Instruments and Service Section, Shops and Electronics and had discussions with Professors and their staffs, met Prof. V.P. Prasad, Deputy Director of I.I.T.
February 6th	P.M.	Left Kharagpur by rail for Calcutta. Arrived Calcutta, met by Joint Director of Agriculture.
February 7th		Calcutta to Panagarh and return by road. Visited D.V.C. Agricultural Research Farm. Discussions with Director, Soil Conservation D.V.C. and Farm Superintending Agriculture Research Farm and visited Farm.
February 8th	A.M.	Calcutta to Canning Town and returned by road. Visited Tubewells, drainage works in delta area and Rice Salinity Sub-center of C.R.R.I.

	P.M.	Meeting with Commissioner, Agricultural & Community Development and Chief Engineer, Irrigation for West Bengal.
February 9th		Left Calcultta for Patna by Air. Met by Director Agriculture-Research, Bihar.
	A.M.	Visited Bihar Agricultural Research Institute, Patna and discussed Irrigation and Soil Management research program.
	P.M.	Visited Bihar Institute of Hydraulic and allied Research, Khaugal (Patna) and reviewed research underway.
February 10th		Patna to Bikram Ganj and return by road. Visited Bikram Ganj, Irrigation Research Station, Tubewells, Indo-Japanese Farm at Arrah.
February 11th Saturday		Patna to New Delhi by Air.
February 12th		Sunday
February 13th & 14th		At New Delhi
February 15th		New Delhi to Agra by road accompanied by Mr. S.V. Dikshit, Subject Matter Specialist, Soil Conservation Agriculture Department. Met by Deputy Directors of Agriculture & Soil Conservation and Assistant Soil Conservation Officer, GOI.
		Visited Balwant Rajput Agricultural College, Bichpuri and its Research Farm.
February 16th		Agra to Kota via Jaipur and Bundi by road. At Jaipur met by Superintending Engineer, Chambal Project and Dr. K.M. Mehta, Rajasthan Canal Project who accompanied the Team to Kota.

		Team was met by Conservator of Forest, Joint Director Agriculture, Soil Conservation Officer, Kota, Joint Director Soil Conservation and other state officials. Visited Matunda Drainage Scheme near Bundhi.
February 17th	A.M.	Visited Soor Sagar Drainage Scheme, Raipura Dharkar Kheri Pilot Project near Kota, Irrigation Research Center, Kota, Closures by formation of Paddocks in Chambal Catchment and GOI Soil Conservation Research Demonstration and Training Center, Kota, Bright Agricultural Farm.
	P.M.	Left Kota for Jodhpur by road. Joint Director Soil Conservation accompanied the Team.
		Met at Jodhpur by the Director Central Arid Zone Research Institute and other state officials.
February 18th		At Jodhpur visited Central Arid Zone Research Institute, its experimental farm and laboratories. State Soil Testing and Soil Salinity Laboratories, Beriganga & Kalyana farms of CAZRI in or near Jodhpur.
February 19th		Left Jodhpur for Ahmedabad (Gujarat) by road. At Ahmedabad Team was met by the Advisor, State Irrigation Department with state officials of Irrigation Department and discussed Shatrunji Irrigation Project, Tubewell irrigation and other developmental programs of State. Left Ahmedabad for Bombay by Air.
February 20th		Left Bombay for Poona by road. Team was met by Joint Director of Agriculture and other state officials at Panwel. Visited State Saline Land Research Station at Panwel, Indo-Japanese Agricultural Demonstration Farm and Agricul-

		tural Research Station, Khopali and Agricultural College, Poona. Had discussions with the Director of Agriculture and his staff. Reviewed work at State Agricultural Meterological Laboratory.
February 21st		At Poona and vicinity visited Grape Garden, Padegaon Sugarcane Research Station, Someswar Lift Irrigation, and Hol Drainage Scheme.
February 22nd		At Poona and vicinity visited Manjri Drainage Project, Subash Cooperative Collective Farming Society, Majri, C.W. & P.C. Field Hydraulic Laboratory, Khadakwasala.
February 23rd	A.M.	Poona to Bombay by road
	P.M.	Left Bombay for Hyderabad by Air. Met at Hyderabad by Dean and Director Research, Andhra Pradesh Agricultural University and other officers of the Agricultural Department.
February 24th	A.M.	Visited Agricultural Research Farm of the Agricultural University and Experimental farm of Irrigation Research Center. Meeting with the Secretary Agriculture, Chief Engineer Irrigation Director of Agriculture and other state officials.
	P.M.	Left Hyderabad for Kurnool by road. Team accompanied by Dean and Director of Agriculture Research, other state officials and Warren Sill, Kansas State University-USAID.
February 25th		At Kurnool visited Department of Agriculture, Irrigation Research Farm at Yemigannur and Irrigation Canal Project and farming operations in area.
February 26th Sunday	A.M.	Left Kurnool for Hyderabad by road.

	P.M.	Left Hyderabad for New Delhi by Air.
February 27th		In New Delhi
February 28th	A.M.	Meeting with John P. Lewis, Minister-Director, USAID.
	P.M.	Third meeting with Deputy Director General and associates, I.C.A.R.
March 1st		Left New Delhi for Madras by Air. Met by Deputy Director Soil Conservation and Agriculture Engineer. Had discussions with Chief Engineer and his staff, visited Soil Mechanics Laboratory, Chepauk.
March 2nd	A.M.	Visited Corporation Sewage Farm, Kodangiyur, Engineering College, Guindy and its Soil Mechanic Laboratory, Hydraulic Laboratory and College Sewage Farm.
	P.M.	Visited Coastal Plantations by car about 25 miles from Madras.
March 3rd		Madras to Pundi and return by road, accompanied by Chief Engineer and his staff. Visited Tubewells, Tanks and State Irrigation Research Center, Pundi.
March 4th	A.M.	Left Madras for Coimbatore via Bangalore by Air. Met by Associate Dean and Professer of Agriculture Engineering and Agricultural Research Engineer.
		Had a meeting with Dean of Agricultural College and Research Council. Examined Research project exhibits.
	P.M.	Visited Agricultural College, its research farm including Horticulture, Canal Seepage, and border furrow irrigation studies, tubewells on College Farm, ICAR Regional Research Station

for Cotton and Sorghum, Agricultural Engineering Workshop, Central Sugarcane Research Institute.

March 5th	A.M.	Coimbatore to Ootacammund and return by road. Visited farms of progressive cultivators and wells and system of irrigation. Visited tropical fruit garden at Kallar and Botanical Garden at Ootacammund. Had discussions with staff of GOI Soil Conservation Research, Demonstration & Training Center, Ootacammund.
	P.M.	Left Coimbatore for Bangalore by Air. Met by Soil Survey Officer and Admn. Asst. Mysore Agricultural University.
March 6th		Bangalore to Krishnarajasagar and return by road. Visited Mandya I.A.D.P. State Sugarcane Research Station and Agriculture Irrigation Research Center, Mandya, Indo-Japanese Farm at Mandya, State Engg. Research Institute, Krishnarajasagar.
March 7th		At Bangalore visited Mysore Agriculture University and its research farms, laboratories, GOI Soil Correlation Laboratory. Had meeting with Vice Chancellor, Dean and other staff of the University.
March 8th		Meeting with Lewis Dawson, University of Tennessee and Group Leader D.M. Thorpe, University of Tennessee-USAID.
		Bangalore to New Delhi by Air.
March 9th		At New Delhi
March 10th		At New Delhi
	P.M.	Meeting with Dale Porter, for Eastern Regional Research Officer, ARS-USDA & staff.

March 11th & 12th Saturday & Sunday		At New Delhi
March 13th		At New Delhi
March 14th		Left New Delhi for Nagpur by Air. Left Nagpur for Jabalpur by road. Met Vice Chancellor Jahawarlal Nehru Agricultural University and Senior Staff of University and Dr. M.B. Russell, University of Illinois-USAID.
March 15th	P.M.	At Jabalpur visited Agricultural University, its research farm and extension farms and vicinity.
	P.M.	Had meeting with Vice Chancellor, Dean and other Research staff of the University. At this meeting Superintending Engineer Irrigation, Director Irrigation Research and staff and Dr. M.B. Russell were present.
March 16th		Jabalpur to Bhopal by road. Dr. Russell accompained Team. Bhopal to New Delhi by Air.
March 17th		At New Delhi
March 18th & 19th Saturday & Sunday		At New Delhi
March 20th	A.M.	New Delhi to Pant Nagar by road. Met by Vice Chancellor and Director of Research. Dr. F.E. Price, Group Leader, University of Illinois-USAID, Dr. Russell and Mr. Minehart. University of Illinois-USAID.
	P.M.	Visited Research Farm of the University.
March 21st	A.M.	Meeting with Vice Chancellor, Director Research, Dr. Price, Dr. Russell and Mr. Minehart.
		Visited Agricultural Engineering Soils and Agronomy Departments of University.
	P.M.	Visited farms of Progressive farmers.

March 22nd		Pant Nagar to Roorkee by road. Met by Mr. A.P. Bhattacharya.
March 23rd		Visited and reviewed research at State Agricultural Research Farm, Dhanauri, State Irrigation Research Institute, Central Building Research Institute.
March 24th		Roorkee to Dehra Dun via Hardwar by road. Executive Engineer, Tubewells accompanied the Team.
		Team was met by Superintending Engineer, Tubewells, GOI Soil Conservation Officers.
	P.M.	Visited Rani-pokhri Tubewell and GOI Soil Conservation Research Demonstration and Training Center.
March 25th	A.M.	Visited Forest Research Institute and College where Team mas met by the President and other Heads of Divisions of Forestry, Education and Biological Research.
	P.M.	Dehra Dun to Mussoorie by road. GOI Soil Conservation Officers accompanied the Team. Enroute visited water-shed management and Slip Stabilization Projects at Rajpura.
March 26th Holi-Sunday		Mussoorie to New Delhi via Saharanpur by road.
Maech 27th & 28th		At New Delhi
March 29th		New Delhi to Hissar by road accompanied by Loyd Johnson, International Rice Research Institute, Manila, Philippines. Met by Dean of Agriculture University, Director Research and other Research officers. Visited research farm and laboratories. Attended Soils Club Meeting and Seminar.

March 30th		Hissar to Rohtak by road. Visited Department of Agricultural Farm at Hansi enroute, visited Agricultural Farm and Soil laboratory of Dr. S.D. Nijhawan at Rohtak.
	P.M.	Rohtak to New Delhi by road.
March 31st		At New Delhi.
April 1st		Fourth meeting with Deputy Director General, ICAR, where Dr. Russell Olson, Dr. M.B. Russell of Jabalpur University, Mr. Ellis Hatt of Ford Foundation, Mr. C.R. Pomeroy and W. Wright of Rockefeller Foundation were present.
April 2nd		Sunday
April 3rd & 4th		At New Delhi
April 5th		New Delhi to Amritsar by Air. Met by Executive Engineer Drainage. Meeting with Superintending Engineer Drainage. Visited Kasur Drain.
	P.M.	Visited Hudiaria main drain.
April 6th		Amritsar to Palampur by road
	A.M.	Met by Director Research, Punjab University, Dean of Agricultural College, Palampur. Deputy Directors Agriculture & Soil Conservation.
	P.M.	Visited water management scheme at Darang.
April 7th		At Palampur
	A.M.	Visited experimental Research farm at Bhadiokar. Sungal Tea Estate, Terracing work in Animal Husbandry Farm and Kuhl system of Neogual Khad in Bandla.
	P.M.	Visited Joti model farm.

April 8th	Palampur to Kulu by road. Visited Nagwain Drainage Project and Progeny Fruit Orchard and Bibal Plantations enroute.
April 9th	Kulu to Simla via Mandi, Sundernagar and Bilaspur by road. Visited projects and Gutkar (Drainage) Consolidation of holding, at Najthyal (well project), Indo-German Project at Bhangrotu and Soil Conservation and Minor Irrigation Project at Naulakha.
	At Simla met by Joint Director of Agriculture
April 10th	At Simla for writing report.
April 11th	Team met Lt. Governor Himachal Pradesh and had discussion with him, Development Commissioner, Chief Secretary, Joint Director of Agriculture, Deputy Director of Agriculture (Soil Conservation).
April 12th	At Simla for writing report.
P.M.	Director of Agriculture had discussion with the Team.
April 13th to 19th	At Simla for writing report.
April 20th	Simla to New Delhi by road.
April 21st	Attended staff meeting of Agriculture Division of USAID.
	Meet with Ford Foundation.
	Fifth meeting with Deputy Director General, ICAR
April 22nd & 23rd Saturday & Sunday	Writing Report
April 24th, 25th & 26th	Writing Report

April 27th		Meeting with Dr. R.V. Tamhane, Joint Commissioner, Soil Conservation, Ministry of Food, Agriculture, Community Development & Cooperation (Department of Agriculture)
April 28th		At New Delhi—Writing Report
April 29th	A.M.	Meeting with Director General, ICAR
	P.M.	Meeting with Minister of Food, Agriculture, Community Development and Cooperation.
April 30th		Team departed for the United States

MAP SHOWING TOUR ROUTES OF WATER USE & SOIL MANAGEMENT RESEARCH CONSULTANT TEAM

APPENDIX 2

Persons contacted by States and locations within States

New Delhi

Govt. of India Ministry of Food, Agriculture, Community Development & Cooperation (Dept. of Agriculture).

1. Mr. Jagjivan Ram—Minister of Food, Agriculture, Community Development & Cooperation.
2. Dr. R.V. Tamhane—Joint Commissioner, Soil Conservation

I.C.A.R.

1. Dr. B.P. Pal, Director General
2. Dr. J.S. Kanwar, Dy. Director General
3. Dr. N. Patnaik, Dy. Agriculture Commissioner
4. Mr. C.S. Sridharan, Dy. Agriculture Commissioner

I.A.R.I.

1. Dr. M.S. Swaminathan, Director
2. Dr. S.S. Bains, Head of Division of Agronomy
3. Dr. N.G. Dastane, Irrigation Division of Agronomy Division
4. Dr. N.P. Dutta, Head of Division of Soil Sciences & Agriculture Chemistry
5. Dr. S.E. Roy, Head of Agriculture Engineering Division
6. Dr. C. Dakshinamurty, Head of Agriculture Physics Division
7. Dr. S.B. Hukkeri, Irrigation Section of Agronomy Division
8. Dr. S. Roy, Irrigation Section of Agronomy Division
9. Prof. Singh, Irrigation Section of Agronomy Division
10. Dr. Y.V. Kathavati, Professor of Agricultural Physics (Division of Agr. Physics)

11. Dr. G.S.P. Krishnamurti, Asst. Physicist, Div. of Agr. Physics

Agra

1. Mr. H.M. Gidwani, Assistant Soil Conservation Officer, Soil Conservation Research & Demonstration Center

Bangalore

1. Mr. R.S. Murthy, Soil Correlator, All India Land Use & Survey Organization
2. Mr. Prabhakara, Senior Cartographic Asst., All India Land Use and Survey Organization
3. Mr. P.K. Abraham, Surveyor, All India Land Use & Survey Organization

Bundi

1. Mr. R. Dyal, Soil Conservation Officer, Soil Conservation Research Demonstration & Training Center, Kota

Coimbatore

1. Dr. Santanam, In Charge, I.A.R.I. Regional Station for Oil Seeds
2. Mr. R. Narashiman, Botanist and Geneticist, Central Sugarcane Research Station

Cuttack

1. Dr. S.Y. Padmanabhan, Director, Central Rice Research Institute
2. Dr. B. Misra Geneticist and Botanist (CRRI)
3. Dr. S. Sampath, Cyto-Geneticist (CRRI)
4. Dr. M.J. Balakrishna Rao, Botanist (CRRI)
5. Dr. R. Seltharaman, Zonal Coordinator (CRRI)
6. Dr. I.C. Mahapatra, Agronomist (CRRI)
7. Dr. S.C. Mathur, Plant Pathologist (CRRI)
8. Dr. N.K. Chakrabarti, Plant Pathologist (CRRI)
9. Dr. P. Israel, Entomologist (CRRI)
10. Dr. Y.S. Rao, Nematologist (CRRI)

11. Mr. S. Patnaik, Agricultural Chemist (CRRI)
12. Dr. S.T. Gaikawad, Soil Chemist (CRRI)
13. Dr. A. Sankaram, Agricultural Chemist Blue Green Algae
14. Dr. S. Govindaswami, Rice Technologist, Blue Green Algae
15. Mr. S.N. Pradan, Agricultural Engineer, Blue Green Algae
16. Dr. K.S. Murthy, Plant Physiologist, Blue Green Algae
17. Mr. C.N. Relwani, Farm Superintendent, Blue Green Algae

Canning Town

1. Mr. R.K. Bhattacharian, Farm Superintendent, Rice Saline Laboratory, Canning Town

Dehra Dun

1. Mr. T.N. Srivastav, President, Forest Research Institute & Colleges
2. Mr. R.C. Kaushik, Director, Forest Education, Forest Research Institute & Colleges
3. Mr. I.N. Qureshi, Director Forestry Research, Forest Research Institute & Colleges
4. Dr. A. Parshotam, Director Biological Research, Forest Research Institute & Colleges
5. Mr. H.C. Dey, Dean, Indian Forest College, Forest Research Institute & Colleges
6. Mr. P.P. Joshi, Forest Utilization Officer, Forest Research Institute & Colleges
7. Mr. B.K. Subha Rao, Senior Research Officer, Forest Research Institute & Colleges
8. Mr. S.K. Gupta, Soil Conservation Officer (E) Soil Conservation Research, Demonstration & Training Center
9. Mr. H.N. Mathur, Soil Conservation Officer (F), Soil Conservation Research, Demonstration & Training Center
10. Mr. Wasiullah, Asst. Soil Conservation Officer (E), Soil Conservation Research, Demonstration & Training Center
11. Mr. R.S. Negi, Research Assistant, Soil Conservation Research, Demonstration & Training Center
12. Mr. M.N. Khybri, Asst. Soil Conservation Officer, Agronomy, Soil Conservation Research, Demonstration & Training Center

Jodhpur

1. Mr. C.P. Bhimaya, Director, Central Arid Zone Research Institute
2. Mr. R.N. Kaul, Head of Resource Utilization Studies Div. (CAZRI)
3. Dr. B.B. Roy. Head of Basic Resource Studies Div. (CAZRI)
4. Dr. C.T. Abichandani, Soil Science Section (CAZRI)
5. Mr. M.N. Misra, Agronomist (CAZRI)
6. Mr. P.N. Puri, Silviculture Section (CAZRI)
7. Dr. G.C. Taneja, Special Animal Studies Div. (CAZRI)

Khadakvasla

1. Mr. C.V. Gole, Director, Central Water Power Res. Station
2. Mr. S.C. Desai, Chief Research Officer

Ootacamund

1. Mr. D.C. Das, Soil Conservation Officer (E) Soil Conservation Research, Demonstration & Training Center, Ootacamund
2. Mr. S.S. Murthy, Statistical Asst. (SCRD&TC)
3. Mr. Shriniwas Asst. Soil Conservation Officer (E) (SCRD&-TC)
4. Mr. A. Cherian, Research Asst. (F) (SCRD&TC)

U.S.A.I.D.

New Delhi

1. Dr. John P. Lewis, Minister-Director
2. Mr. William C. Ide, Deputy Director
3. Dr. Russell O. Olson, Chief, Agriculture Division
4. Mr. Oliver A. Bauman, Dy. Chief, Agriculture Division
5. Mr. John T. Phelan, Chief, Soil & Water Branch
6. Mr. James R. Coover, Soil & Water Branch
7. Mr. U.S. Madan, Soil & Water Branch
8. Dr. John L. Malcolm, Input Branch
9. Dr. A.R. Downie, Chief, Agriculture Production Promotion
10. Mr. J.A. Rigney, Regional Researcher

11. Mr. R.J. Davis, Soil Agronomist
12. Mr. K.E. Gibson, Entomologist
13. Mr. Peter VanSchaik

Bangalore

University of Tennessee/U.S.A.I.D.

1. Dr. D.M. Thrope
2. Dr. Lewis Dawson (on official visit from Tennessee)

Bhubaneswar

University of Missouri/U.S.A.I.D.

1. Dr. D. McKinsey

Hyderabad

Kansas State University/U.S.A.I.D

1. Dr. A.D. Webber
2. Dr. Warren H. Sill
3. Mr. W.G. Amstein

Jabalpur

University of Illinois/U.S.A.I.D.

1. Dr. M.B. Russell

Pani Nagar

University of Illinois/U.S.A.I.D.

1. Dr. F.E. Price
2. Mr. D.J. Minehart
3. Mr. A.E. Thompson

Ford Foundation

1. Dr. D. Ensminger
2. Mr. Ellis L. Hatt
3. Mr. Byron Bondurant
4. Mr. Ralph Brownscombe

5. Mr. Nathan Koffsky
6. Mr. Donald Green
7. Mr. Rey M. Hill

Rockefeller

1. Dr. Guy B. Baird
2. Dr. Ralph Cummings
3. Mr. C.R. Pomeroy, Agriculture Engineer
4. Dr. B.C. Wright

A.R.S.

1. Dr. Dale Porter, Far Eastern Regional Research Officer, ARS/USDA
2. Mr. Clyde F. Rainwater

Andhra Pradesh

Hyderabad

1. Dr. C.H. Krishnamurti, Director Research
2. Dr. T.R. Mehta, Dean, Andhra Pradesh Agr. University
3. Mr. G.H. Shankar Reddy, Divisional Soil Conservation Officer (Research) Anantpur
4. Mr. C. Siptapati Rao, Divisional Soil Conservation Officer Headquarters
5. Mr. M.A. Qadir, Secretary, Food & Agriculture
6. Dr. T.V. Reddy, Director of Agriculture, A.P.
7. Dr. Iqbal Ali, Director, Engineer Research Department
8. Mr. V.G. Palnitkor, Reader, College of Engineering, Osmania University

Yemnigannur

1. Mr. P.L. Narjanappa, Executive Engineer

Bihar

Patna

1. Dr. S.C. Mandel, Director, Research Dept. of Agriculture

2. Dr. H.N. Pandey, Agriculture Engineer, Irrigation Research
3. Mr. V.B.P. Singh, Asst. Agriculture Engineer, Irrigation Research Farm
4. Mr. M.P. Sinha, Agriculture Field Experimental Specialist
5. Dr. S.Q. Haque, Asst. Plant Pathologist, Agricultural Research Institute
6. Mr. S.A. Kulkarni, Asst. Botanist (ARI)
7. Mr. H.N. Bakshi, Asst. Agriculture Engineer (ARI)
8. Mr. C.K.N. Sinha, Director, Bihar Institute of Hydraulic and Allied Research, Khagaul
9. Mr. R.L. Dewan, Dy. Director, Bihar Institute of Hydraulic and Allied Research, Khagaul

Bikramganj

1. Mr. K.K. Mukerjee, Asst. Agronomist, Agriculture Irrigation Research Farm

Arrah

1. Mr. Y. Hirosaki, Leader Japanese Team

Damodar Valley Corporation *(Panagarh)*

1. Dr. P. Sen, Director, Soil Conservation, Hazaribagh
2. Mr. H.D.N. Prasad, Farm Superintendent, Panagarh Farm

Gujarat

Ahmedabad

1. Dr. R.P. Talati, Advisor and Consultant to the State Irrigation Department
2. Mr. Bapat, Executive Engineer, Irrigation

Haryana

Hissar

1. Dr. D.R. Bhumbla, Dean, College of Agriculture, Hissar
2. Dr. Sukhdev Singh, Director of Research, P.A.U., Hissar

3. Dr. G.S. Sekhon, Associate Professor Soils, College of Agr., Hissar
4. Dr. N.S. Randhawa, Associate Professor Soils, College of Agr., Hissar
5. Dr. I.P. Abrol, Soil Physicist, College of Agriculture, Hissar
6. S.S. Prihar, Associate Professor of Soil Physics, College of Agriculture, Hissar
7. Dr. S.S. Khanna, Associate Professor of Soils, College of Agriculture, Hissar
8. Dr. G.S. Bhandari, Associate Professor of Soils, College of Agriculture, Hissar
9. Dr. G. Dev, Soil Science Experimental Specialist, College of Agriculture, Hissar
10. Mr. D.S. Rana, Asst. Soil Chemist, Soil Testing Laboratory
11. Dr. M.K. Moolani, Professor of Agronomy

Hansi

1. Mr. Gurmel Singh Sidhu, Director of Agriculture, Haryana
2. Mr. Sube Singh Rana, Dy. Director of Agriculture, Hansi

Rohtak

1. Ch. Hukam Singh, Principal, Jat College, Rohtak
2. Prof. Sahi, Professor of Botany, Jat College, Rohtak
3. Prof. Bhatia, Professor of Chemistry, Jat College, Rohtak

Himachal Pradesh

Palampur

1. Dr. H.R. Kalia, Dean, College of Agriculture, Palampur
2. Dr. G.S. Sehhon, Professor Soils, P.A.U., Hissar
3. Mr. K.S.K. Rao, Dy. Director Agriculture (Soil Conservation), Himachal Pradesh
4. Mr. B.M. Batra, Dy. Director of Agriculture, Palampur
5. Mr. Bachint Singh, Asst. Soil Conservation Officer
6. Mr. K.K. Mahajan, Research Asst., Bhadhiarkar Farm
7. Mr. Bishamber Dass, Proprietor, Sangul Tea Estate & Progressive Farmer

8. Mr. Ishwar Das Sud, Proprietor, Joti Model Farm at Bari
9. Brig Bhandari, Darang Tea Estate
10. Mrs. Bhandari, Darang Tea Estate
11. Mr. Butel, M.L.A., Proprietor, Bandla Tea Estate

Mandi

1. Mr. D.N. Zutshi, Project Officer, Indo-German Project
2. Mr. M.M. Narang, Asst. Soil Conservation Officer, Sundernagar

Kulu

1. Mr. K.V. Rao, Asst. Soil Conservation Officer
2. Mr. Mohindar Singh Pabla, Horticulture Assistant
3. Mr. Gurbachan Singh, Secretary, Inter State Soil Conservation Board, Punjab, H.P., U.P., Rajasthan and Jammu & Kashmir States
4. Mr. M.P. Gupta, Conservator of Forests
5. Mr. J.C. Tandon, Conservator of Forests
6. Dr. M.S.L. Vaidya, Divisional Forest Officer, Kulu
7. Mr. R. Malhotra, Divisional Forest Officer, Seraj

Simla

1. Mr. V. Vishwanathan, Lt. Governor, H.P.
2. Mr. M.C. Sharma, Chief Secretary, H.P.
3. Mr. B.S. Singh, Development Commissioner & Secretary Agriculture, H.P.
4. Dr. L.S. Negi, Director of Agriculture, H.P.
5. N.R. Kaura, Joint Director of Agriculture, H.P.
6. Mr. Kocher, Assistant Marketing Officer, H.P.
7. Mr. O.P. Bari, Soil Conservation Inspector, Hqr.

Indian Institute of Technology, *Kharagpur*

1. Prof. V.N. Prasad, Deputy Director
2. Mr. A.C. Pandya, Head of Department of Agriculture Engineering
3. Mr. B.N.P. Ghildayal, Asst. Professor, Dept. of Agriculture Engineering

4. Mr. C. Gopinath, Asst. Professor, Dept. of Agr. Engineering
5. Mr. Radhe Lal, Asst. Prof., Dept. of Agr. Engineering
6. Mr. T.P. Ojha, Asst Prof., Dept. of Agr. Engineering
7. Mr. H.K. Pande, Asst. Prof., Dept. of Agr. Engineering
8. Mr. J. Visweswara Rao, Head of Dept. of Civil Engineering
9. Mr. S.K. Ghose, Asst. Professor, Dept. of Civil Engineering
10. Mr. B N. Neogy, Asst. Prof., Dept. of Civil Engineering
11. Mr. N. Roy, Asst. Prof., Dept. of Civil Engineering
12. Mr. S.N. Ghosh, Lecturer, Dept. of Civil Engineering
13. Mr. V.V. Jayaraman, Lecturer, Dept. of Civil Engineering
14. Mr. S.K. Mazumdar, Lecturer, Dept. of Civil Engineering
15. Mr. M. Nageswara Rao, Lecturer, Dept. of Civil Engineering
16. Mr. C.R.S. Pillai, Lecturer, Dept. of Civil Engineering
17. Mr. B.S. Rama Rao, Lecturer, Dept. of Civil Engineering
18. Mr. G.L.N. Sastry, Lecturer, Dept. of Civil Engineering
19. Mr. K. Srinivasan, Lecturer, Dept. of Civil Engineering
20. Mr. D. Bhagavantum, Associate Lecturer, Dept. of Civil Engineering
21. Mr. G.S. Sanyal, Head of the Dept of Electronics and Electrical Communication Engineering
22. Mr. C.P. Gupta, Lecturer, Farm Machinery

Madhya Pradesh

Jabalpur

1. Dr. J.S. Patel, Vice Chancellor, Jawahar Lal Nehru University
2. Dr. D.P. Motiramani, Director Research
3. Dr. S.V. Arya, Dean, Agricultural Engineering
4. Mr. S.L. Vishnoi, Director of Extension
5. Dr. P.M. Tamboli, Agricultural Chemistry
6. Dr. S.D. Choubey, Prof., Agronomy
7. Dr. S.C. Jethmalani, Agrostologist
8. Dr. N. Hat
9. Mr. V.M. Chitale, Superintending Engineer, Narbada Canal
10. Mr. P.L.N. Murthy, Director Irrigation, Bhopal
11. Mr. B.R. Ranga, Assistant Engineer, Irrigation, Bhopal
12. Mr. Kallu Singh, Progressive Farmer Village Panagars
13. Mr. D.V. Rao, Executive Engineer, Bhopal

Maharashtra

Panvel

1. Mr. R.C. Srivastav, Joint Director of Agr. Res. & Education
2. Mr. S.V. Naikwade, Dy. Director of Agriculture
3. Mr. J.R. Kakade, Sugarcane Specialist, Padegaon

Khopali

1. Mr. B.B. Patil, Agronomist, Agricultural Research Station

Poona

1. Dr. M.B. Ghatge, Director of Agriculture, Maharashtra
2. Dr. V.G. Vaidya, Additional Director of Agriculture, Maharashtra
3. Mr. M. Gangopadya, Director, Agricultural Meterology
4. Mr. R.V. Satpute, Jt. Director of Agriculture (Engineering)
5. Dr. R.L. Nagpal, Jt. Director of Agriculture (Horticulture)
6. Dr. S. Soloman, Principal, Agricultural College, Poona
7. Mr. C.K. Zende, Associate Professor of Soil Science, Poona
8. Mr. K.V. Joshi, Chief Soil Survey Officer
9. Mr. S.R. Bagal, Dy. Director of Agriculture Research & Education
10. Mr. K.R. Sahasrabudhe, Agronomist, Dept. of Agriculture
11. Mr. S.S. Vanjori, Agricultural Engineer, Dept. of Agriculture
12. Mr. G.K. Patwardhan, Chief Sugarcane Development Officer
13. Mr. N.A. Phadnis, Horticulturist, Dept. of Agriculture
14. Mr. S.M. Sathe, Executive Engineer, Decan Canal Drainage Div.
15. Mr. S.P. Kulkarni, Executive Engineer, Irrigation Div., Poona
16. Dr. T.L. Deshapanda, Soil Specialist, Sholapur
17. Dr. N.K. Ghumare, Divisional Soil Conservation Officer
18. Mr. H.C. Tiwari, Pool Officer, C.S.I.R.
19. Mr. K.S. Parandhe, Khar Land Investigator, Saline Land, Research Station, Panvel
20. Mr. G.R. Tatawawadi, Rice Specialist, Agr. Research Station, Khopali
21. Mr. B.B. Patel, Agronomist, Agr. Res. Station, Khopali

22. Mr. Sueji Ota, Project Leader, Indo-Japanese Demonstration Farm

Walhar

1. Mr. H.N. Shah, Proprietor, Grape Garden

Padegaon

1. Mr. R.S. Patil, Agronomist, Sugarcane Research Station
2. Mr. R.A. Kale, Research Officer
3. Mr. S.M. Patil, Sugarcane Physiologist, Sugarcane Res. Station
4. Mr. B.C. Gogate, Statistician, Sugarcane Research Station
5. Mr. S.V. Chinchorkar, Biochemist, Sugar Research Station
6. Dr. S.J. Randwe, Soil Physicist, Sugarcane Research Station

Nira

1. Mr. S.M. Upplekar, Advisor to Someshwar Cooperative Sugar Factory

Madras

Madras

1. Mr. J.E. Vaz, Chief Engineer, Irrigation, Madras
2. Mr. K.S. Hegde, Principal Engineering College, Guindy
3. Mr. M. Umpathy, Agricultural Engineer (Implements & Tractor)
4. Prof. T. Parthasarthy, Public Health
5. Prof. T.G. Srinivasan
6. Mr. B. Sundersesan, Associate Professor
7. Mr. G. Ekambaram, Associate Professor
8. Prof. V. Kalyanaraman
9. Mr. M. Nalluswami, Asst. Professor
10. Mr. N.V. Pundarikotnthan
11. Mr. A.E. Santhappan, Executive Engineer, Chingleput
12. Mr. M. Hagesan, Asst. Engineer, Chingleput
13. Mr. T.S. Francis, Joint Director (Extension)
14. Mr. S. Narayanaswami, Agriculture Engineer, Soil Conservation
15. Mr. P.K. Radhakanth, Agriculture Engineer, Drilling
16. Mr. S. Srinivasan, Section Mechanic, Tubewells

17. Mr. P. Sivadasan, Junior Engineer
18. Mr. P. Kumaraswamy, Research Officer
19. Mr. S. Shanmugham, Executive Engineer
20. Mr. N. Pinágapany, Sewage Development Officer
21. Mr. Varadarajan, Drainage Engineer
22. Mr. Ramaswamy Reddy, Superintending Engineer, Irrigation Dept.
23. Mr. W.S. Winnfread, Executive Engineer, Soil Mech. Lab. Chepauk
24. Mr E.G. Sivaswami, Joint Director, Agriculture

Coimbatore

1. Dr. B.W.X. Ponnaiya, Dean of the Agricultural College and Research Institute & Additional Director
2. Dr. K. Ramakrishnan, Associate Dean, Agriculture College and Research Institute
3. Dr. M. Srinivasan, Professor of Agriculture Economics, Agriculture College and Research Institute
4. Dr. D. John Durairaj, Professor of Soil Science, Agriculture College and Research Institute
5. Mr. A. Dhanapalan Mosi, Reader in Soil Science, Agriculture College and Research Institute
6. Mr. J. Samuel Sundararaj, Reader in Horticulture, Agriculture College and Research Institute
7. Mr. R. Kalappa, Reader in Agronomy, Agriculture College and Research Institute
8. Mr. V. Srinivasan, Paddy Specialist, Agriculture College and Research Institute
9. Mr. K. Kannaiyan, Cotton Specialist, Agriculture College and Research Institute
10. Mr. M.K. Lingiah, Extension Specialist, Agriculture College and Research Institute
11. Mr. K.R. Raman, Horticulturist and Associate Professor of Horticulture, Agriculture College and Research Institute
12. Mr. K.M. Sundaram, Argonomist and Associate Professor of Agronomy, Agriculture College and Research Institute
13. Mr. R. Soundararajan, Soil Chemist, Agriculture College and Research Institute

14. Mr. S. Venkatachalam, Soil Chemist, Radio Isotope Section, Agriculture College and Research Institute
15. Mr. C. Ratnam, Soil Survey Officer, Agriculture College and Research Institute
16. Dr. M. Ramachandran, Associate Professor of Agr. Economics, Agriculture College & Research Institute
17. Mr. R.K. Shivanappan, Professor of Agriculture Engineering, Agriculture College and Research Institute
18. Dr. C.V. Govindaswamy, Professor of Plant Pathology, Agriculture College and Research Institute
19. Mr. S.E. Anantharaman, Agricultural Engineer, Agriculture College and Research Institute
20. Mr. Henry David, Superintending Engineer, Irrigation
21. Mr. Santhasham, Executive Engineer, Irrigation
22. Mr. K.R. Nagaraja Rao, Secretary, Research Council
23. Mr. S.P. Ganesan, Botanic Garden Assistant
24. Mr. V. Ramakrishnan, Assistant Botanist
25. Mr. T.N. Palaniswami, Progressive Farmer of Muruganathan
26. Mr. S.M. Kalyanaraman, Retired Cotton Specialist

Kallar

1. Mr. M.C. Appaujan, Asst. Horticulturist, Metrapalayum
2. Mr. S. Sambanda Murthy, Asst. Horticulturist, Metrapalayum
3. Mr. S. Venkatesan, Research Assistant, Metrapalayum
4. Mr. T. Balasubramanian, Fieldman, Metrapalayum
5. Mr. D. Perumal, Fieldman, Metrapalayum
6. Mr. V. Palaniswamy, Asst. Horticulturist, Ootacamund
7. Mr. S. Sankaran, Fieldman, Metrapalayum
8. Abdul Rahman, Fieldman, Metrapalayum

Ootacamund

1. Mr. B.G. Narayana Menon, Curator, Botanic Gardens, Ootacamund

Mysore

Bangalore

1. Dr. K.C. Naik, Vice Chancellor, Bangalore Univ. of Agriculture Sciences

2. Dr. G. Rangaswami, Dean, Bangalore University of Agr. Sciences
3. Dr. N.P. Patil, Director of Research, Bangalore University of Agriculture Sciences
4. Dr. N.G. Perur, Professor of Agr. Chemistry & Soils, Bangalore University of Agriculture Sciences
5. Dr. S.V. Patil, Professor of Agronomy, Bangalore University of Agriculture Sciences
6. Dr. R.F. Patil, Professor of Agriculture Engineering, Bangalore University of Agriculture Sciences
7. Dr. K. Krishnamurthy, Associate Professor of Agronomy, Bangalore University of Agriculture Sciences
8. Dr. P.B. Deshpande, Associate Professor of Chemistry, Bangalore University of Agriculture Sciences
9. Dr. H. Eswarappa, Asst. Professor of Chemistry, Bangalore University of Agriculture Sciences
10. Dr. A.S. Hadimani, Asst. Chemist, Bangalore University of Agriculture Sciences
11. Mr. B.V. Venkata Rao, Soil Chemist, Bangalore University of Agriculture Sciences
12. Mr. H.G. Abdul Hamid, Superintending Engineer, Irrigation, Mysore Circle
13. Mr. D.V. Murty, Soil Survey Officer, Dept. of Agriculture
14. Mr. B.N.M. Hegde, Adm. Asst., Agr. University
15. Dr. G.N. Kulkarni, Asst. Agronomist, Agriculture University
16. Mr. N.Paramesisarappa, Research Asst., Agriculture University
17. Mr. G. Halappa, Research Asst., Agriculture University
18. Mr. G.M. Lingarajan, Farm Superintendent, Agr. University

Bangalore

19. Mr. N. Sunkareddy, Instructor in Chemistry & Soil, Agr. University
20. Mr. K.N. Viswashwaraiah, Asst. Soil Chemistry, Agr. University

21. Mr. S.K. Kenchannagonda, Instructor in Chemistry & Soil

Mandya

1. Mr. Ghouse Mohiyuddin, Deputy Director of Agriculture
2. Mr. Bhim Sanachar, Executive Engineer, Dam
3. Mr. K. Siddaiah, Executive Engineer, Irrigation
4. Mr. M.R. Shivanna, Asst. Engineer, Minor Irrigation Research
5. Mr. D. Rangamannar, Asst. Director of Agr.
6. Mr. Syed Ahmed, Asst. Engineer, Irrigation Research Drainage Sub-Division
7. Mr. S.K. Patil, Sugarcane Specialist, Agriculture Res. Station
8. Mr. Haryyoshi Tanaka, Agronomist, Indo-Japanese Group
9. Mr. Tsugio Suzuki, Engineer, Indo-Japanese Group
10. Mr. K. Narayan, Farm Manager, Indo-Japanese Group
11. Mr. Britto, Asst. Information Officer (Agriculture)
12. Mr. M.R. Ramasethy, Junior Engineer, Irrigation
13. Mr. C.T. Muthanna, Agriculture Information Officer

Krishnarajasagar

1. Dr. D. Dodiah, Director, Irrigation Research Station
2. Mr. B.S. Gopalakrishna, Asst. Engineer, Irrigation Res. Station
3. Mr. S. Govindaraj, Executive Engineer, Irrigation Res. Station
4. Mr. Syed Ahmed, Asst. Engineer, Irrigation Research Station
5. Mr. P.V. Somasekhav, Executive Engineer, Irrigation Res. Station
6. Mr. H.B. Sobadegowda, Asst. Engineer, Irri. Res. Station

Orissa

Bhubaneswar

1. Dr. K. Ramiah, Vice Chancellor, Orissa Agriculture University
2. Dr. B.N. Sahu, Professor, Agronomy
3. Mr. H.K. Mohanty, Director, Minor Irrigation Department.
4. Mr. A.R. Panda, Joint Director, Agriculture

Sambalpur

1. Mr. P.R.C. Patro, Superintending Engineer, Hirakud Dam
2. Mr. A.B. Jena, Chief Research Officer

3. Mr. G.S. Sarma, Executive Engineer, Main Dam
4. Mr. L.R. Misra, Asst. Engineer, Irrigation
5. Mr. B. Misra, Dy. Director, Project Officer, I.A.D.P.
6. Mr. A.B. Rishi, Soil Chemist, Irrigation Research Center, Attibara (Chakuli)
7. Mr. S.K. Mohanty, Plant Physiologist, Irrigation Research Center, Attibara (Chakuli)
8. Mr. A.C. Jena, Senior Research Assistant
9. Mr. P.K. Mohonty, Engineering Overseer
10. Dr. S. Patnaik, Joint Director, Soil Conservation, Orissa
11. Mr. M. Gangopadhya, Director, Agricultural Meterology, Poona
12. Dr. Gupta, Dy. Director, C.W.P.C.
13. Mr. S.K. Khallilulah, Senior Research Assistant
14. Mr. B.M. Samanth Roy, Senior Research Assistant
15. Mr. D.C. Nath, Senior Research Assistant
16. Mr. B.C. Muduli, Indo-Japanese Farm Manager

Punjab

Amritsar

1. Mr. I.P. Kapila, Director Land, Reclamation, Irrigation & Power Research Institute
2. Mr. Kailash Chander, Superintending Engineer, Drainage
3. Mr. M.K. Narasimhaiya, Executive Engineer, Land Reclamation Irrigation & Power Research Institute
4. Dr. S.R. Sehgal, Mathematical Officer
5. Dr. Gajinder Singh, Hydraulic Officer
6. Mr. M.M. Lal Malhotra, Land Reclamation Officer
7. Mr. Kehar Singh, Executive Engineer, Drainage Division
8. Mr. Puri, Executive Engineer, Drainage Division
9. Mr. A.N. Sharma, S.D.O.
10. Mr. B.D. Sharma, Asst. Research Officer, Hydraulic
11. Mr. Umrao Singh, Asst. Research Officer, Hydraulic
12. Mr. H.S. Garewal, S.D.O., Hydraulic
13. Mr. T.C. Paul, Asst. Research Officer, Hydraulic
14. Mr. A.N. Kotwal, Asst. Research Officer

Ludhiana

1. Dr. C.M. Jacob, Dean, Agricultural Engineering
2. Mr. A.M. Michael
3. Mr. Murti
4. Dr. N.S. Randhawa, Associate Professor, Soil Fert, Soil Chemistry
5. Dr. P.N. Takkar, Asst. Professor of Soil Chemistry
6. Mr. B.R. Arora, Asst. Prof., Soil Fertility
7. Mr. P.C. Batra, Asst. Prof., Agronomy (Soil Conservation)
8. Mr. Bhagwan Dass, Asst. Soil Chemistry, I/C Soil Testing Lab.
9. Dr. J.S. Grewal, Asst. Soil Chemist, Micronutrient Scheme
10. Dr. G.S. Bedi, Agriculture Information Officer

Rajasthan

Jaipur

1. Mr. R.S. Singh, Superintending Engineer, Chambal
2. Dr. K.M. Mehta, Project Director, Rajasthan Canal, Bikaner

Bundi

1. Mr. Nandan Bhargav, Conservator of Forests, Chambal Catchment
2. Mr. I.S. Sharma, Jt. Director of Agriculture, Kota
3. Mr. R. Dyal, Soil Conservation Officer, Soil Conservation Research, Training & Demonstration Center

Kota

1. Mr. Udebhan Singh, Agronomist, Irrigation Research Center

Jodhpur

1. Dr. Ranbir Singh, Joint Director of Agriculture (Soil Conservation), Jodhpur
2. Mr. B.B. Verma, Dy. Director of Agriculture, Jodhpur
3. Mr. C.K. Garg, Research Asst., Soil Testing Lab., Jodhpur
4. Mr. O.P. Sharma, Research Asst., Salinity Lab., Jodhpur

Uttar Pradesh

New Delhi

1. Mr. S.V. Dikshit, Subject Matter Specialist, Soil Conservation Agriculture Department, Lucknow

Agra

1. Mr. Rais Dulah Khan, Dy. Director of Agriculture
2. Mr. K.B. Singh, Dy. Director of Agriculture (Soil Conservation)
3. Dr. M.L. Gupta, Prof. of Extension and Farm Superintendent, B.R. College, Bichpuri (Agra)
4. Mr. Rattan Kumar Singh, Asst. Prof. of Agronomy, B.R. College, Bichpuri (Agra)

Dehra Dun

1. Mr. D.D. Sanwal, Superintending Engineer, Tubewells, Meerut
2. Mr. S.C. Varma, Asst. Engineer, Tubewells, Saharanpur
3. Mr. S.V.S. Singh, Executive Engineer, Tubewells, Muzafarnagar

Pant Nagar

1. Mr. D.P. Singh, Vice-Chancellor, U.P. Agriculture University
2. Dr. R.L. Palliwal, Director of Research
3. Dr. H.S. Seth, Associate Prof., Hydrology
4. Dr. Jaswant Singh, Prof., Agricultural Engineering
5. Dr. Maharaj Singh, Associate Prof., Soil & Water Management
6. Mr. G.B. Johri, Asst. Director, Land Management Scheme
7. Col. Lal Singh, Progressive Farmer
8. Dr. Munsha Singh, Progressive Farmer

Roorkee

1. Dr. S.P. Garg, Director, Irrigation Research Institute & Research Farm

2. Mr. A.P. Bhattacharya, Statistician, Irrigation Research Institute & Research Farm
3. Mr. Amar Singh, Farm Superintendent, Dhanauri Experimental Farm
4. Mr. B.P. Srivastava, Asst. Research Officer, Dhanauri Experimental Farm
5. Mr. Gupta, Irrigation Research Institute
6. Mr. P.L. Dey, Central Building Research Institute

West Bengal

Calcutta

1. Mr. R. Ghosh, Commissioner, Agri. & Community Development
2. Dr. K. Sengupta, Additional Director of Agriculture
3. Mr. Sengupta, Joint Director of Agriculture
4. Dr. M.N. Bosak, Agriculture Chemist
5. Mr. R.B. Chakravarty, Chief Engineer, Irrigation

APPENDIX 3

Chronological Listing of Soil & Water Research, Demonstration and Other Projects visited (See also Attached Map)

1. GOI I.A.R.I. *(New Delhi)*
2. State Irrigation & Power Research Institute at *Amritsar* and *Malikpur* (Punjab)
3. Punjab Agricultural University, Soil & Water Management Research Work, *Ludhiana*, (Punjab)
4. GOI Central Rice Research Institute at *Cuttack* (Orissa)
5. Orissa Agricultural University, Soil & Water Management Research Work, *Bhubaneswar* (Orissa)
6. State Attabira Irrigation Research Center at *Sambalpur* (Orissa)
7. Indo-Japanese Demonstration Project at Chakauli, *Sambalpur* (Orissa)
8. Hirakud Dam, Reservoir and Canal system, *Sambalpur* (Orissa)
9. Hirakud Research Station, Soil Mechanics and Foundation Engineering, *Sambalpur* (Orissa)
10. Indian Institute of Technology, Soil & Water Management Research Work at *Kharagpur* (West Bengal)
11. D.V.C. Agricultural Research Farm, Soil & Water Management Works at *Pannagarh* (West Bengal)
12. GOI sub-station of Central Rice Research Institute for Saline areas at *Canning* (West Bengal)
13. State Agricultural Research Institute, *Patna* (Bihar)
14. State Irrigation Research Center at *Khagaul* near Patna (Bihar)
15. State Agricultural Irrigation Research Farm at *Bikramganj* (Bihar)

16. Indo-Japanese Demonstration Project near *Patna* (Bihar)
17. Agricultural Research Farm at B.R. Agricultural College, *Bichpuri* near *Agra* (U.P.)
18. State Water-logging Project near *Bundi* (Rajasthan)
19. State Irrigation Research Center at *Kota* (Rajasthan)
20. State Project for Pasture Development (Paddocks) for protection of Chambal catchment at *Kota* (Rajasthan)
21. GOI Soil & Water Conservation Research, Training and Demonstration Center at *Kota* (Rajasthan)
22. GOI Central Arid Zone Research Institute, *Jodhpur* (Rajasthan)
23. State Soil Testing & Soil Salinity Laboratories at *Jodhpur* (Rajasthan)
24. State Saline Land Research Station at *Panwel* (Maharashtra)
25. Indo-Japanese Agricultural Demonstration Farm & Agricultural Research Station, *Khopali* (Maharashtra)
26. Agricultural College, *Poona*, (Maharashtra)
27. State Sugarcane Research Station at *Padegaon* (Maharashtra)
28. State Hol Drainage Scheme near *Poona* (Maharashtra)
29. Manjri Drainage Project near *Poona* (Maharashtra)
30. Agricultural Meteorological Laboratory at *Poona* (Maharashtra)
31. GOI Field Hydraulic Laboratory of C.W.&P.C. at *Poona* (Maharashtra)
32. Andhra Pradesh Agricultural University, Soil & Water Management Research Work at Hyderabad (A.P.)
33. State Irrigation Research Center at *Yemigannur* near *Kurnool* (A.P.)
34. State Hydraulic & Soil Mechanics Laboratory at *Guindy* (Madras)
35. State Sewage Irrigation Farm at (*Madras*)
36. State Research Station at *Pundi* (Madras)
37. State Soil Mechanic Laboratory, Engineering College *Chapauk* (Madras)
38. State Tubewells and tanks around *Madras*
39. Agricultural College *Coimbatore*, Soil & Water Management Research Work (Madras)

40. Someswar Lift Irrigation Project near *Nira* (Poona Dist., Maharashtra)
41. GOI Regional Station for Oilseeds (I.A.R.I.) at *Coimbatore* (Madras)
42. GOI Central Sugarcane Research Center at *Coimbatore* (Madras)
43. Kallar Tropical Fruit Reserch Farm at *Metrupalayam* (Madras)
44. State Botanical Gardens *Ootacammund* (Madras)
45. Mysore Agricultural University, Soil & Water Management Project Research Work at *Bangalore* (Mysore)
46. State Sugarcane Research Station, Soil & Water Management Research Work at *Mandya* (Mysore)
47. Indo-Japanese Demonstration Farm at *Mandya* (Mysore)
48. State Engineering Research Institute at *Krishnarajasagar* (Mysore)
49. GOI Soil Correlation Laboratory, *Bangalore* (Mysore)
50. Jawaharlal Nehru Agricultural University, Soil & Water Management Research Work at *Jabalpur* (M.P.)
51. U.P. Agricultural University, Soil & Water Management Research Work at *Pantnagar* (U.P.)
52. State Irrigation Research Institute & Research Farm at *Roorkee* (U.P.)
53. GOI Soil Conservation Research, Training & Demonstration Center at *Dehra Dun* (U.P.)
54. GOI Watershed Management & Slip Stabilization Work at *Rajpura* near *Dehru Dun* (U.P.)
55. Tubewells in *Dehra Dun* (U.P.)
56. GOI Forest Research Institute & Colleges, *Dehra Dun* (U.P.)
57. Punjab Agricultural University, Soil & Water Management Research Work at *Hissar* (Haryana)
58. State Agricultural Farm at *Hansi* (Haryana)
59. State Agricultural Farm at *Rohtak* (Haryana)
60. Dr. S.D. Nijhawan's Laboratory at *Rohtak* (Haryana)
61. State Drainage Project in *Amritsar* District (Punjab)
62. Agricultural Research Farm, Tea Gardens and Agricultural Farm at *Palampur* (H.P.)
63. Indo-German Drainage Project near *Kulu* (H.P.)

64. Indo-German Drainage Project and Tubewells, Contour consolidation near *Sundar Nagar* (H.P.)

APPENDIX 4

List of all significant Research Stations in India dealing with the Water, Water Use, and Soil Management Research

Name & Address of Institution	Agency managing the Institution	Type of Research work undertaken
1	2	3
I. Central Research Stations		
(1) Indian Agricultural, Research Institute, New Delhi	Indian Council of Agricultural Research	Plant-water relationship, consumptive use, evapotranspiration, water requirements of different crops, moisture studies, drainage.
(2) Central Rice Research Institute, Cuttack	-do-	Consumptive use, water requirements of rice, puddling.
(3) Central Arid Zone Research Institute, Jodhpur	-do-	Fixation and stabilization of sand dunes, control of wind erosion by windbreak shelterbelts, strip cropping relating to wind direction, mulch, moisture conservation.

1	2	3
(4) Soil Conservation Research, Demonstration Training Center, Dehra Dun	Ministry of Food & Agriculture, Community Development & Cooperation (Dept. of Agri.) now under transfer to I.C.A.R.	Different types of terraces, grass waterways, loss of soil, runoff of water, control of bank erosion, gully control, stablization of slips, runoff from watersheds under different management, and engineering, afforestation and agronomic practices to reduce runoff and soil loss.
(5) Soil Conservation Research, Demonstration Training Center, Chandigarh	-do- Now under transfer to I.C.A.R.	Different types of terraces, runoff form watersheds under different management, agronomic, afforestation & engineering practices to reduce runoff and soil loss.
(6) Soil Conservation Research, Demonstration & Training Center, Kota	-do-	Ravine and gully reclamation, agronomic, engineering and afforestation practices to reduce runoff and soil loss.
(7) Soil Conservation Research & Demonstration Center, Agra	-do-	Different types of terraces, grass water ways, gully and ravine reclamation, agronomic, afforestation and engineering practices to reduce runoff and soil loss.
(8) Soil Conservation Research and Demonstration Center, Vasad	Ministry of Food & Agriculture, Community Development & Cooperation (Dept. of Agriculture) now under transfer to I.C.A.R.	Different types of terraces, grass waterways, gully and ravine reclamation, agronomic, afforestation and engineering practices to reduce runoff and soil loss.

1	2	3
(9) Soil Conservation Research, Demonstration & Training Center, Bellary	Ministry of Food & Agriculture, Community Development & Cooperation (Dept. of Agri.) now under transfer to I.C.A.R.	Soil & water management of black cotton soil, size and type of bunds; infiltration study, agronomic, afforestation and engineering practices to reduce runoff and soil loss, conservation of soil moisture.
(10) Soil Conservation Research, Demonstration & Training Center, Ootacammund	-do-	Soil & water management on steep slopes with heavy rainfall, different types of terraces with grass waterways, agronomic, afforestation and engineering practices to reduce runoff and soil loss, runoff studies under different types of vegetation.
(11) Soil Conservation Research & Demonstration Station, Ibrahimpattan	-do-	Soil & water management of Red Soils, size and type of bunds, agronomic, afforestation and engineering practices to reduce soil loss and rnnoff.
(12) Soil Conservation Research & Demonstration Station, Chatra	-do-	Soil & water management of hilly steep slopes, study of sediment load from streams, agronomic, afforestation & engineering practices to reduce soil loss and runoff.

1	2	3
(13) Soil Correlator Center for Alluvial Soil, New Delhi	Ministry of Food & Agriculture ,Community Development & Cooperation (Dept. of Agri.) now under transfer to I.C.A.R.	Soil survey, land use and land classification correlation. Soil classification.
(14) Soil Correlator Center for Central Black Soil, Nagpur	-do-	-do-
(15) Soil Correlator Center for Southern Black & Red Soils, Bangalore	-do	-do-
(16) Soil Correlation Center for Eastern Lateritic Soil, Culcutta	-do-	-do-
II. State Research Stations		
(1) Soil Conservation Research & Demonstration Station, Rehmankhera	Department of Agriculture, Uttar Pradesh	Soil & water management of alluvial soils, different types of bunds and terraces, agronomic, engineering and afforestation practices to reduce soil loss and runoff.

1	2	3
(2) Agricultural College, Kanpur	Department of Agriculture, Uttar Pradesh	Plant-water relationship, water requirement of different crops, evapotranspiration, moisture studies, saline & alkaline reclamation.
(3) Irrigation Research Institute & Research Farm, Roorkee	Dept. of Agriculture, Uttar Pradesh. Also some schemes financed by ICAR and Central Board of Irrigation & Power	Plant-water relationship, evapotranspiration, water requirement of wheat and paddy, sedimentation and soil studies.
(4) Land Reclamation Irrigation & Power Research Institute, Amritsar	Dept. of Irrigation, Punjab. Also some schemes financed by Central Board of Irrigation & Power	Land reclamation and ground water studies. Canal lining, seepage, plant-water relationship, evapotranspiration, saline and alkaline reclamation, drainage.
(5) Salinity Laboratory, Jodhpur	Department of Agriculture, Rajasthan	Pot studies about saline and alkaline reclamation.
(6) Irrigation Research Center, Kota	-do-	Plant-water relationship, water requirement of different crops, drainage.
(7) Bihar Institute of Hydraulic & Allied Research, Khagaul (Patna)	Department of Irrigation, Bihar. Also some schemes financed by Central Board of Irrigation and Power	Canal lining and tubewells.

1	2	3
(8) State Agricultural Research Institute, Patna	Department of Agriculture, Bihar	Pathology studies, screen paddy varieties, research on paddy.
(9) Agricultural Irrigation Research Farm, Bikramganj	-do-	Water requirements of different crops, Plant-water relationship.
(10) Shifting Cultivation Research Center	Soil Conservation Wing of Forest Department, Assam	Soil & water management of lands under shifting cultivation by terracing, raising of cash crops, etc.
(11) Irrigation Research Center, Attabira (Sambalpur)	Department of Agriculture, Orissa. There is a proposal for ICAR to take over this Center	Water requirements of different crops, moisture studies, puddling.
(12) Soil Conservation Research & Demonstration Center, Koraput	Soil Conservation Wing of Department of Agriculture, Orissa	Soil & water management of red soils, agronomic engineering and afforestation practices to reduce runoff and loss of soil.
(13) Irrigation Research Center, Yemigannur (Kurnool)	Department of Agriculture, Andhra Pradesh. There is a proposal for ICAR to take to over this Center.	Water requirements of different crops. moisture studies (Station not fully developed).

1	2	3
(14) Sugarcane Research Station, Padegaon (Poona)	Department of Agriculture, Maharashtra	Water requirements of different crops particularly of sugarcane, plant-water relationship.
(15) Soil Conservation Dry Farming Research Station, Sholapur	-do-	Soil & water management of black cotton soil, dry farming technique for rainfed areas.
(16) Agricultural College, Coimbatore	Department of Agriculture, Madras	Water requirements of different crops, plant water relationship, lining of channels.
(17) Irrigation Research Station, Poondi	Department of Irrigation Madras. Also financially assisted by Central Board of Irrigation & Power	Lining of field channel, tubewells, sedimentation studies in reservoirs and evaporation.
(18) I.A.D.P., Mandya	Department of Agriculture, Mysore	Water requirements of different crops, moisture studies.
(19) Mysore Engg. Research Station, Krishnarajasagar	Department of Irrigation, Mysore	Canal lining.
(20) Gujarat Engg. Research Station, Baroda	Irrigation Department, Gujarat. Also financed by the Central Board of Irrigation and Power	Ground water studies.

1	2	3
(21) Research Institute, West Bengal, Calcutta	Department of Irrigation, West Bengal. Also some schemes financed by the Central Board of Irrigation and Power	Sedimentation studies.
(22) Agricultural College, Poona	Department of Agriculture, Maharashtra	Water requirements of different crops.
(23) Agricultural College, Anand	Department of Agriculture, Gujarat	
III. Autonomous Bodies		
(a) Agricultural Universities		
(1) Punjab Agricultural University, Ludhiana and Hissar	State Agricultural Department, Punjab and Haryana & ICAR. There is proposal for ICAR to take over Hissar Center	Plant-water relationship, water requirements of different crops, moisture studies, saline and alkaline reclamation, drainage, lining of field channels, evapotranspiration, weed control.
(2) Agricultural University, Bhubneswar	State Agricultural Department, Orissa and I.C.A.R.	Plant-water relationship, water requirements of different crops, moisture studies.

1	2	3
(3) Andhra Pradesh Agricultural University, Hyderabad	State Agricultural Department, Andhra Pradesh & I.C.A.R.	Plant-water relationship, water requirements of different crops, moisture studies.
(4) Agricultural University, Mysore, Bangalore	State Agricultural Department, Mysore and I.C.A.R.	Plant-water relationship, water requirement of different crops, moisture studies.
(5) Jawaharlal Agricultural University, Jabalpur	State Department of Agriculture, Madhya Pradesh and I.C.A.R.	Plant-water relationship, water requirement of different crops, moisture studies, drainage, weed control.
(6) U.P. Agricultural University, Pant Nagar	State Department of Agriculture, U.P. and I.C.A.R.	Plant-water relationship, water requirement of different crops, moisture studies and tubewells.
(7) Rajasthan Agricultural University, Udaipur	State Department of Agriculture, Rajasthan and I.C.A.R.	Soil and water studies.
(8) Kalyani Agricultural University, Kanchrapara	State Agricultural Department, West Bengal and I.C.A.R.	
(*b*) *Autonomous bodies*		
(1) I.I.T., Kharagpur	Ministry of Education, Some schemes financed by I.C.A.R.	Plant-water relationship, water requirement of different crops, moisture studies, evapotranspiration.

1	2	3
(2) D.V.C. Agricultural Research Farm at Panna-garh, W. Bengal	Damodar Valley Corp. under Ministries of Irrigation & Power and Food & Agriculture, Community Development and Cooperation	Plant-water relationship, water requirement of different crops.
(3) Agricultural Research Farm, B.R. Agricultural College, Bichpuri (near Agra)	B.R. Trust, also receives financial assistance from State Agricultural Department, U.P.	Plant-water relationship, water management of different crops.
(4) Damodar Valley Corp., Maithon, Bihar	Damodar Valley Corp. under Ministry of Irrigation & Power. Also receives assistance from Central Board of Irrigation & Power	Sedimentation studies on reservoirs.

APPENDIX 5

Estimates of Proposed Expenditures by the GOI, Ministry of Food & Agriculture, for Soil & Water Conservation Research in the Fourth Five-Year Plan

Scheme	Fourth Plan Outlay 5 Year Total	1967-68	Average per Year
	Thousands of Rupees		
ICAR (Centrally and Centrally sponsored) Institutes	125,893	—[1]	25,179
ICAR:			
Coordinated Projects:			
(1) Agronomic Experiments	25,000	800[2]	5,000
(2) New Cropping Patterns	6,267	[3]	1,255
(3) Soil Structure	1,600	363[4]	320
(4) Microbial Decomposition	1,189	277[4]	238
(5) Soil Tests & Crop Response	1,434	508[4]	287
(6) Micronutrients	2,000	532[4]	400
(7) Irrigation Res. in River Valley Project	2,100	—[3]	420
(8) Central Soil Salinity Lab.	5,952	—[5]	1,195
(9) Studies of soil salinity, irrigation drainage, soil science, & water management	7,922	—[5]	1,585
Soil Cons. Research (9 stations)	5,150	1,030[6]	1,030
Grants to State Govts.	1,600	320[6]	320
Dept. af Agriculture Minor Irr. Pro. Research	6,000	—[1]	1,200
Totals	66,250	3.830	13,250

1. Unavailable 2. Provisional allocation 3. Under consideration 4. Allocated 5. No action 6. Proposed

APPENDIX 6

State Satistics on Irrigation—Acres Supplied by Canals, Tanks, Wells, etc ; Electric and diesel Pump-sets ; Number of Private, Cooperative, and State Tubewells Constructed and Anticipated through Third Five-Year Plan.

1. Net Area Covered by different Sources of Irrigation Water in 1961 (1000 Acres)

State	Canal	Tanks	Wells	Others	Total
Andhra Pradesh	3,290	2,844	810	244	7,218
Assam	899	-(a)	—	634	1,533
Bihar	1,608	799	646	2,042	5,095
Gujarat	163	32	1,403	90	1,688
Jammu & Kashmir	633	—	12	32	677
Kerala	450	79	35	315	879
Madhya Pradesh	1,128	309	811	85	2,333
Madras	2,179	2,320	1,478	151	6,128
Maharashtra	597	476	1,509	105	2,687
Mysore	652	889	370	362	2,273
Orissa	973	1,031	59	508	2,571
Punjab	5,426	16	2,426	72	7,967
Rajasthan	1,436	530	2,507	124	4,597
Uttar Pradesh	4,944	1,036	5,898	661	12,539
West Bengal	1,922	910	39	468	3,339
Delhi	33	—	—	97	130
Himachal Pradesh	—	—	—	97	97
Manipur	168	—	—	—	168
Tirupura	—	2	—	30	32
Totals	26,501	11,473	18,039	6,127	61,930

Gross Irrigated Acreage (Adjusted for multi-cropping) is 70,079,000 Acres

The 1965-66 Total Gross Irrigated Area is estimated at 82 million acres.

(Ref. B. p 42)

Fertilizer Statistics—1994-65

(a) (—) Not available

2. Number of Electric & Diesel Pumpsets for Open Wells by States[1]

State	Electric	Diesel	Total
Andhra Pradesh	37,024	53,940	90,964
Assam	51	1,376	1,427
Bihar	4,530	5,687	10,217
Gujarat	14,225	74,982	89,207
Jammu & Kashmir	12	20	32
Kerala	4,565	4,272	8,837
Madhya Pradesh	10,228	15,681	25,909
Madras	118,481	43,832	162,313
Maharashtra	23,530	98,747	122,277
Mysore	24,433	22,587	47,020
Orissa	129	1,703	1,832
Punjab	18,774	14,648	33,422
Rajasthan	10,477	5,464	15,941
Uttar Pradesh	17,969	25,908	43,877
West Bengal	256	5,637	6,893
Union Territories	471	460	931
Total	285,164	374,944	660,108

1. Private Communication from Minor Irrigation Division of Ministry of Food & Agriculture, Department of Minor Irrigation.

3. Number of Tubewell Installations Anticipated During the Third Five Year Plan[1]

State	Private	Coop.	State	Filter point	Artesian	Total
Andhra Pradesh	—	—[(a)]	25	—	265	290
Assam	—	—	20	—	—	20
Bihar	450	220	—	—	—	670
Gujarat	—	—	500	—	—	500
Jammu & Kashmir	—	—	—	—	—	—
Kerala	—	—	—	—	—	—
Madhya Pradesh	—	—	57	—	—	57
Madras	2,700	—	—	2,193	150	5,043
Maharashtra	—	—	—	—	—	—
Mysore	—	—	—	—	—	—
Orissa	40	—	30	100	—	170
Punjab	6,430	—	32	—	—	6 462
Rajasthan	120	—	70	—	—	190
Uttar Pradesh	2,000	—	1,500	—	—	3,500
West Bengal	150	—	500	—	—	650
Delhi Territory	35	—	25	—	—	60
Other Territories	—	—	3	50	—	53
Total	11,925	220	2,762	2,343	415	17,665

1. (Ref. 16, p. 54)
(a) (—)=Not availale.

4. Number of Private, Cooperative, and State Tubewells Constructed During the First and the Second Five-Year Plans and Anticipated During the Third Five-Year Plan[1]

Plans	Private	Coop.	State	Filter point	Artesian	Total
Pre-Plan	N.A.	N.A.	N.A.	N.A.	N.A.	3,500
I-Plan	3,000	N.A.	2,900	3,000	200	9,100
II-Plan	4,500	N.A.	3,800	3,000	200	11,500
III-Plan	11,925	220	2,762	2,343	415	17,665
Total	19,425	200	9,462	8,343	815	41,765

1. (Ref. 16, p. 24, 68).

APPENDIX 7

Comments on Scheme for Chemical Control of Aquatic Weeds In Irrigation Canals

March 20, 1967

Dr. J.S. Kanwar
Dy. Director General
ICAR
Ministry of Food and Agriculture
Krishi Bhavan
New Delhi

Sub : Scheme on Chemical Control of Aquatic Weeds in Irrigation Canals of Madhya Pradesh

Dear Dr. Kanwar :

Reference is made to the subject scheme, a copy of which was given us during our discussions of February 28, 1967. Subsequently, we visited Jawaharlal Nehru Agricultural University, Jabalpur, Madhya Pradesh and submit the following recommendations on the above subject.

Although the weed problem in canals, tanks, and conveyance channels as viewed during our trip to Rajasthan and Madhya Pradesh is most serious, the University at Jabalpur in our opinion does not now have the scientific facilities or staffing in the disciplines needed to conduct an aggressive research program on this problem.

The Agronomist, S.S. Pathak, who submitted the scheme, is now Assistant Director with the Department of Agriculture at Indore, Madhya Pradesh. Professor of Agronomy, S.D. Choubey who would currently supervise this scheme at the University, while competent as to the training and experience in crop culture and management,

would need considerable backing from other disciplines if this scheme is to be launched with reasonable expectation for practical successes.

Considerable research on use of chemicals for control of aquatic weeds is now underway outside India and maximum consideration of the results so far achieved should be made before similar research is undertaken here.

For example, the University of California, Davis, Department of Botany has sponsored an active continuing weed control research program for many years. More recently, problems of plant growth in water distribution systems and drainage channels have been included. The Agricultural Research of the U.S. Department of Agriculture has a long history of accomplishment on this problem in cooperation with the U.S. Bureau of Reclamation.

In spite of the large amount of research on such problems, no easy solutions have been forthcoming so far. However, as with insecticides, new chemicals are emerging continually. Effectiveness in aquatic weed control may eventually be achieved but it will be through the effort of many disciplines working in concert.

This project should start by a thorough survey and evaluation of the literature on the subject, and a full time staff should be committed to the study program. Anything less is not apt to be effective because of factors influencing fish life, drinking water for humans and animals, along with possible damage to irrigated crops. All of these matters will have to be identified and evaluated thoroughly before recommendations for use can be made. The task is large and it must be undertaken with all due appreciation that this is the case.

Our recommendation is that if ICAR sponsors this scheme, the following conditions should be met :

1. An inter-disciplinary approach involving at least three scientists—one each with good training in plant physiology, biochemistry, and irrigation-drainage systems are needed.

2. Weed control research should be their principal activity.

3. A thorough evaluation of work already undertaken elsewhere should be the first step to be taken.

4. The research project should be developed as a coordinated scheme between the Ministries of Food and Agriculture (ICAR) and the Irrigation and Power (Central Board of Irrigation and Power) and should also involve both the Department of Agriculture and Irrigation and the University in the State(s). The recommendation is based on the fact that the aquatic weed problem is a concern and problem of all these and other groups.

5. The objectives and proposed procedure for the research, as outlined in the scheme, are vague and lack specificity. A more definitive "plan of action" should be developed.

6. The research should be undertaken at a location where the problem is most acute, preferably at a location where scientific competence can be made available. Initially, control of all types of aquatic plants need not be undertaken. Instead, principles of control by chemicals for the primary plant types should receive the emphasis. The activity should be concentrated at only one location in India and when preliminary indications of successful control by various chemicals are indicated, testing or evaluations should be made at various locations such as the Irrigation Research Centers throughout the country. If the scheme is undertaken, it should be implemented at IARI (Indian Agricultural Research Institute).

We should be pleased to discuss these recommendations more fully should you so desire.

Sincerely yours,
sd/
Chester E. Evans
Leader
Soil & Water Management
Research Consultant Team

APPENDIX 8

Interim Recommendations on Research Relating to Irrigated Areas of River Valley Projects in India.

March 17, 1967

Dr. J.S. Kanwar
Dy. Director General
Indian Council of Agriculture Research
Ministry of Food and Agriculture
Krishi Bhavan
New Delhi

Sub: Scheme for Establishment and Research in Irrigated Areas of River Valley Projects with particular attention to the Research Farm of Damodar Valley Corporation at Pannagarh, West Bengal

Dear Dr. Kanwar:

Persuant to Dr. N. Patnaik's letter of February 9, 1967 and our discussions of February 28, 1967, we make the following recommendations to ICAR relative to the above subject:

Solution to India's food shortage is indeed a problem of the highest possible urgency. Positive and significant progress must be made in the next two years. We feel the scheme for the establishing of Irrigation Research Centers, if implemented under the following conditions, would contribute greater impetus to this goal than any other one research activity in prospect. This is "Adaptive Research". The growers of food need "facts", and this type of research will help provide the information needed.

It is axiomatic that to make something successful, we must put everything together in its proper combination. Use of land and water

resources, all over the world, are not now being utilized to their maximum potential. This is the challenge and we must therefore gear our research toward accomplishing this goal.

1. The objective of this research should be to determine the most economical combination (evaluated in terms of gains in productivity) of irrigation practices, fertilizations, cropping sequences, and social circumstances, including marketing, to fit each significant major soil and climatic areas that exist in India. If implemented and carried out on a sound experimental basis, these schemes should do much to accomplish this objective.

Considerable effort on fertilization, new crops and cropping practices is currently underway. The effort in soil and water management needs to be stimulated and upgarded.

II Schemes for Irrigation Research in River Valley Project Areas :

Irrigation Research Center, Kota (Chambal Command Area)

The Chambal command area supported by the Gandhi Sagar, Rana Pratap Sagar and Kota dams has been designed to supply water from the Kota Barrange to 1.1 million acres in Rajasthan and 350,000 acres in Madhya Pradesh. This command covers 498,995 acres (54.3 percent) of deep heavy loams, 168,107 acres (22.2 percent) of shallow soils of less than 1-foot depth; 58,847 (7.7 percent) of soils with impeded subsoil drainage; and 33,035 acres (4.3 percent) high pH, sodium-dominated saline soil. Water has been made available through the system since 1960. Already, near the canal routes, there are obvious examples of raised water tables which have come to the surface in some of the older farms, filled dug wells, and reached foundations of houses. To meet these sudden contingencies, drainage projects are being initiated. Some success has been achieved on a small scale in reversing the waterlogging process.

The crux of the matter from the point of view of effective research and demonstration is the great speed with which introduction of irrigation has produced indisputable, visible symptoms of the inevitable end result that irrigation systems cannot last indefinitely without provision for adjunct drainage.

Establishment of the experimental farm was recommended in 1958 in order to solve irrigation problems anticipated when the characteristically fine-textured soils with impervious subsoils were placed under irrigation. The 75-acre farm supporting the Research Center was started in 1965. It is still being put into shape and some research projects are underway. The urgency for research und development has been amplified by general recognition that useable management information is required now if irrigation is to serve the purposes intended in the Chambal command.

Land and water management research undertakings for the Chambal area have implications for other extensive areas throughout central India, because wherever fine-textured, swelling black soils occur, the elements of infiltration rates, and critical moisture status required for tillage seeding and plant emergence will have much in common. Good research which can explain soil responses in terms of moisture as related to physical, chemical and agronomic characteristics of these soils will be transferable elsewhere.

The research phases being programmed for the center at Kota consist of soil studies, agronomic studies, reclamation of saline and alkali land, engineering studies, and plant pathology. It has been judged* that 75% of the land in the Chambal command belongs to the category of drainage needs which the Irrigation Research Center at Kota represents.

One interesting and pertinent project is a study of practices evolved on cultivated farms having been irrigated previously from wells and tanks. Plans call for visiting 200 such farms each year, 75 Kharif operations and 125 rabi operations will make up the total.

Weeds in conveyance chanals are an acknowledged problem which must be given significant attention since efficiencies of water distribution have fallen below design expectations. Control measures to minimize seepage losses are further subjects for instensive study.

The Chambal command area is a dynamic, fast-changing example

*C.f. Report on the inspection of the Irrigation Research Center, Kota Rajasthan. J.S. Bali, Dy. Advisor, Soil Conservation (1964).

of the hazards in irrigation agriculture. The evidence has been compressed into a very short period of a few years rather than the usual slow accumulations of problems which may not become prominently displayed for 50 years or more.

The Pannagarh Agricultural Research Farm

The facility of 225 acres, located about 110 miles northwest of Calcutta has 185 acres under cultivation. It is operated by the Damodar Valley Corporation. At present, it is the only available facility in West Bengal where irrigation responses can be measured and evaluated through experimentation. Crops being grown on the farm are rice, jute, sugarcane, and wheat. Experiments are under way with high yielding varieties of wheat and rice. Potato culture has not been successful.

Experiments on consumptive use of water have just been started. Sprinkler irrigation may have advantages for the area, but equipment is not available.

The State of West Bengal is committed to a number of irrigation development schemes. Tubewell construction is being emphasized with 1473 installations having been completed by the State. Explorations have been conducted over much of the State, tapping down to 750 feet. A total of 4000 deep tubewells are now considered to be practicable. River lift irrigation systems, improved tanks and shallow wells are being encouraged as potential means for adding to the total supplies of useable water. The State provides a subsidy of 45% of development cost of private wells if they produce useable water.

The agronomic problems associated with irrigation developments in West Bengal lie in getting faster maturing varieties of paddy because if a wheat crop can be grown following paddy, the bonus is very large. Wheat is essentially a new crop for the area. Therefore, it is essential that application research in irrigation, fertilization, and handling of wheat and other rabi crops be pursued with vigor.

Other research programs in progress at Pannagarh involve the management of irrigation on soils with high water table, techniques

for draining, considerations of plant diseases and the effects of irrigation on soil properties.

Studies underway relate to sowing and planting dates, varietal trials, permissible cropping intensities and fertilizer responses. Information on optimum planting dates is desired in order to adjust the dates for canal water flows.

In view of the great potential for expanding rabi crops through irrigation of coastal low lands, we recommend to the Indian Council of Agricultural Research that it sponsor research in land and water management at the Pannagarh Agricultural Research Farm in West Bengal. The intensification of rabi cropping in regions of "excess water" holds enormous potential for increasing food production on lands which otherwise remain idle.

The Tungabhadra Project Development and Demonstration Farm Kurnool District, Andhra Pradesh

This farm was established in 1955 and consists of 76 acres, of which 66 are cultivated. Personnel at the center include four technical staff—Agronomist in charge, Assistant Agricultural Engineer, Soil Chemist, and Assistant Statistician.

The stated objective of the Farm is to conduct research on irrigated crops on the Andhra Pradesh side of the Tungabhadra Project and provide continuity of agricultural research work done at Saruguppa now in Mysore State.

The Tungbhadra Project is supplied by a low level canal bf 236 miles length, of which 155 miles is in Mysore State. The water is stored in reservoir on the Tungbhadra River.

The localized command area in Andhra Pradesh consists of 148,867 acres, of which 37,765 are "irrigated wet" and 111,102 acres are "irrigated dry", The annual command area under the low level canal in Andhra Pradesh is 240,563 acres.

Temperatures reach 110°F for several weeks during rabi. Precipitation averages 22-25 inches annually, approximately 65% of which occurs from June to September. Geographically, the area is distant

from the coastal bolt, separated by a low range of hills and, consequently, receives only the "residual effects" of the monsoons.

The project transgresses Andhra Pradesh and Mysore States and as such the canal and command areas are separately administered by the respective States. The design discharge of the canal as it enters Andhra Pradesh is 730 cusec at full canal depth of 6′ 5″. Actual flow is 600 to 640 cusec. Since the localized, command area is based on 730 cusec, which is never realized, the need for judicious use of water is self-evident. Also, the lower level canal furnishes water to 30 tanks with a command area of 2206 acres.

The special feature of the Tungabhadra Project is to extend irrigation to as many villages as possible with a view to providing protective irrigation which serves as an insurance against recurring famines. Localized relatively small command areas are distributed widely over the region. Originally, the intent was to provide water under the low level canal for the nine-month period of June to February. However, water is now furnished for 11 months and this is expected to continue, at least until after the high level canal is built. The prospect of reducing the period of water delivery to nine months presents a special problem needing evaluation and solution.

The mean duty of water for "irrigated dry" crops is taken as 160 and that for wet crops (paddy) as 50. It would appear desirable to bring the maximum area under crops such as groundnut, cotton, and sorghum which would require only about one-third as much irrigation water.

The localized areas are about 53% black soils, 19% red soils, and the balance is mixed. Black soils are high in clay and require special management practices for optimum production of crops. Waterlogging is occurring and drainage problems are developing as more irrigation water is applied to the project. In some commands, the soils occur on gentle slopes and are severely eroded. Land levelling is necessary before effective irrigation can be achieved.

The Chakuli (Attabira) Irrigation Research Center

This Center consists of 40 acres of land. Plans are to increase

the acreage to 200. Personnel at the Center include 13 technical positions, six of which are for specialists. Posts of the Engineer and Statistician and some research assistants are vacant.

The stated research objective of the Center is to study agricutural problems of the Hirakud Irrigation Project, Sambalpur district of Orissa, consisting of approximately 380,000 acres kharif and 220,000 acres rabi crops.

The Hirakud Project consists of a reservoir behind the Hirakud Dam across the Mahanadi River, and the Bargarh and Sason canals and distributaries from which nearly 4,500 cusecs of irrigation water are delivered annually. Other sources of irrigation water from tanks, katas, wells, and diversion weirs are also available in the District, which in addition to the some 400,000 acres under the canal system, makes an annual irrigation area of about 2,540,000 acres.

The elevation of the irrigation project area is about 500 feet and less. Temperatures range from 45° to 115°F. The annual precipitation averages 62 inches, 85% of which falls from June to September. About 75% of the precipitation on the watershed occurs as runoff flow at Hirakud Dam.

The Hirakud canal system was designed on the basis of the following accepted cropping patterns :—

Kharif Season			
	(a) Paddy	70%	266,000 acres
	(b) Sugarcane	10%	38,000 ,,
	(c) Millet, pulses, oilseed	20%	76,000 ,,
		Total	380,000 acres
Rabi Season			
	(a) Paddy	35%	133,000 acres
	(b) (medium water duty) maize, groundnut vegetables	17%	64,000 ,,
	(c) (large water duty) pulses, oilseed	6%	23,000 ,,
		Total	220,000 acres

The command area of the Hirakud irrigation project has an undulating topography interpersed with hills and valleys. The irrigated area consists of a series of ridges, slopes, dales, and valleys. Soils are brown to red in color and are derived mainly from gneiss or schist parent materials. Soils vary widely in physical and chemical characteristics and this together with slope differences usually give rise to a wide array of problems when subjected to irrigation agriculture. The ridges and slopes are well drained, but drainage in the dales and bottoms is only fair. The drainage problem is, however, becoming aggravated by increased irrigation. Lower lying lands often suffer from waterlogging attributed to overirrigation on upper lands.

The distribution of precipitation (85% of the 62 inches annually occurring frome June to September) makes supplemental irrigation a necessity not only in rabi season but also during the kharif season to assure successful harvest of crops.

Special problems in land and water management of the project area include : (1) High seepage losses from canals and distributaries. These result in severe losses of water, and also cause waterlogging of lands adjacent to the conveyance channels. (2) There is no quantitative measure of the irrigation water used by cultivators. (3) Fields near the canal become overirrigated because the prevailing irrigation practice of passing water from field to field necessitates that water pass over these fields on its way to the lower ones. (4) The undulating topography, small fields, and varied cropping patterns aggravate the water use and distribution problem.

General Consideration

1. *Objectives and Plan of Work* should be clearly stated. The objectives are good, but plans for accomplishing them should be more specific.

2. *Where support should be directed*: In India as elsewhere, financial support is more effective if it is in a limited number of key locations. Accordingly, the following is recommended :

(1) Because of the complexity of problems and their magnitude, we recommend that first consideration (ahead of Pannagarh,

West Bengal) be given to the Kota, Rajasthan Chambal River Project. We understand that FAO might be planning to support this project. If this FAO support materializes, the priority for ICAR support for this research would be reduced somewhat.

(2) Pannagarh, West Bengal—Subject to (1) above—This is a real need, but personnel must be assured that they will be associated with a scientific community and a research atmosphere In order to make maximum progress.

(3) Yemigannur (near Kurnool), Andhra Pradesh—This is one of 3 of 37 former "research" stations not yet transferred to the University at Hyderabad. Although we did not assess the overall implications of transfer, we feel that transfer of research to the University is a step in the right direction.

The level of understanding of objectives to which this station is directed is indeed at a low level. Construction of the physical plant should be moved forward at a rapid pace. Only the "Black Cotton Soil" is represented adequately on the station. The conditions for ICAR support for this station as recommended by the team would include :

(a) Transfer of the activity to the University at Hyderabad.

(b) Acquisition of additional land representative of the "red" soil zone for studies of irrigation needs for and production potentials of various crops, particularly groundnut.

(c) Shift the objective of the station for "testing" to "adaptive" research.

(d) The leadership of the research (engineering) program would be vested in a proven scientist having competence in soil and water engineering.

(4) At Chakuli (Attabira) Orissa for Hirakud Project—A modest research effort on land adjacent to the Indo-Japanese Rice Demonstration farm is underway. Potential for productive research is good and we recommend strengthening as proposed under the ICAR coordinated scheme for irrigation research. The sta-

tion is now under the Department of Agriculture. We believe that alignment of the research at Chakuli under the Agricultural University, Bhubneswar, would be desirable from the standpoint of needed technical guidance and direction of the research.

(4) At Markan (Bihar) for Gandak Project—This station was not visited. However, the Agricultural Farm, Bikramganj, Shahabad District was visited and this research was reviewed. The Team was impressed with the potentials of the staff and the location for research if the work were adequately supported.

(6) Hissar, Haryana—This Irrigation Research Center has not as yet been visited; therefore no recommendations are made at this time.

III. Scientific Capability—In some instances people on the staff are not adequately research oriented. This should be a primary requirement of all personnel. One of the Class I Officers should be given a special increase in pay and designated "Officer in Charge" of the Research Station. In the proposed staffing pattern, the Agronomist is the logical choice, but only if he has had research experience and/or training in irrigation. Otherwise, the Agricultural Engineer with irrigation experience as distinguished from power and machinery should lead the programs at Irrigation Research Centers. However, whoever is designated to be in charge should have had training in either soil and water management or irrigation and drainage.

Also, pay for all Class I Officers should be such that positions at Irrigation Research Centers are fully competitive in all respects with positions available at larger institutions. The importance of the work demands personnel of highest competence, and the pay and pre-requisites must be made attractive to outstanding candidates.

Sincerely yours,
Chester E. Evans
Leader
Soil & Water Management
Research Consultant Team

APPENDIX 9

Status of Current Research in Waterlogging and Associated Salinity Problems in India with Map Showing Saline & Alkali Lands in India

1. Extent of the Problem in Terms of Acreage and Intensity

Water Table Within 5 Feet

State	Waterlogged	Waterlogged saline	Saline & alkaline with low water table
(Area in hundreds of thousands of acres)*			
Punjab	25.00	17.50	12.50
Uttar Pradesh	18.89	8.00**	23.00
West Bengal	—	21.0 (Coastal)	—
Delhi	0.09	0.37**	—
Maharashtra	0.20	2.5 (Coastal) 10.75**	—
Andhra Pradesh	—	0.20. (Coastal)	0.37
Madras	—	0.08 (Coastal)	0.025
Kerala	—	0.38 (Coastal)	—
Orissa	—	10.00 (Coastal)	—
Mysore	—	5.5 (Coastal)	4.5
Madhya Pradesh	—	3.00**	3.00**
Rajasthan	—	—	10.00**
Bihar	—	—	0.10
Gujarat	—	30.00 (Coastal)	—

* Exact information regarding the areas involved is not available. The above are approximate areas but give the relative intensity of the problem in the different States.

** Fluctuating Water Table.

2. Intensity of Water logging and Salinity

Waterlogging became serious in India following the introduction of canal irrigation. After the construction and use of the Ganga Canal opened in 1854, it was observed in Uttar Pradesh that soils were deteriorating due to salinity. Twenty years later the Reh Commission was appointed (1876) to look into the problem. The Reh Commission suggested the lowering of water tables by deepening the canals, preventing overirrigation and draining out subsoil water. It was concluded that the causes for the creation, spread and intensity of soil salinity and alkalinity resided within the soil itself and that solutions for checking the spread of salinization or for reclaiming the land should be sought within the soil. Since the Commission's report, some action has been taken to check salinity increases, but even so, the area of land affected continued to increase as shown by investigations made in 1912 and again in 1952.

At the present time, waterlogging problems are most serious in the Punjab, followed by states of Rajasthan, Maharashtra, Mysore, Jammu & Kashmir and Delhi. Information is not available for other states. Detailed information regarding the extent of waterlogging and rates of increase are available for the state of Punjab where this problem is acute. The total area where water tables are 0 to 5 feet is 3,813,838 acres of which 1,300,000 acres are saline.

In portions of the area commanded by the Chambal River Project in Rajsthan, water tables rose to acute problem dimensions in a short period of seven years. Irrigation from this project was started in 1960. In 1964 the areas in which water tables were within five feet were 18,000 acres in June, and 71,000 acres in October after the monsoon. In June 1965 the area of less than 5 feet water tables had decreased to 40,000 acres. But, the area increased to 110,000 acres in October after the 1965 monsoons.

In Maharashtra and Mysore, within two years of executing the Nira and Pravara Rivers irrigation projects, rising water tables were observed. Waterlogging and salt damage to lands irrigated by canal from the Godavari river were noticed a few years after the

opening of first Decan canal in 1884. However, no corrective measures were adopted till 1948 when 77,000 out of 219,000 acres in the command area had become unsuitable for cultivation. Of the former, 57,000 acres were salt affected. The salt damaged area increased to about 86,000 acres in 1952 when steps were taken to lower water tables. In 1963 28,721 acres had water tables of 0 to 5 ft. Of these, 17,900 acres contained excessive salt. Where water tables were between 5 ft. and 10 ft., 53,744 acres were salt damaged.

In Delhi, the waterlogged areas with water tables from 0 to 5 ft. and 5 to 10 ft. have been reported to be 3,200 and 6,000 acres, respectively.

3. Steps Taken to Control Waterlogging

To control waterlogging, attempts have been made to reduce seepage by lining canals; to drain away surface waters; to drain subsoils by installing surface open drains and tile drains, and by tubewell pumping from the underlying water table.

Surface drains—Work on surface drains was started in 1955 in the states of Assam, Punjab, Uttar Pradesh, Bihar, West Bengal and in the lower deltaic part of Orissa. Except for Maharashtra where work had been started prior to 1955, the Punjab is the only state with extensive drains. Very little drainage work has been done in the remaining states probably due to lack of sufficient field data and inadequate organization.

In the *Punjab* both main drains and subsidiary drains are operating. One of Punjab's drainage systems was inspected at Amritsar where subsidiary drains 3 to 5 miles apart have been collecting water from surrounding fields. Considerable progress has been made in the Punjab where more than 160,000 acres have been reclaimed after installing surface drains.

In *Rajasthan* drainage work has been started recently in the Chambal Command area and construction of main drains and field drains is in progress. Field drains 1.5 ft. deep and 2 ft. wide with

average spacing of 220 ft. and 0.25% grade were being constructed at the time of visit of the Team.

In *Maharashtra* a good drainage system consisting both of open surface and subsurface tile or pipe drains has been developed in the canal irrigated area. Generally open drains have been installed but in some more valuable lands growing sugarcane or other cash crops, pipe and tile drains have been installed.

The Hol drainage scheme which was begun in January, 1952 was completed in August, 1956. This reclaimed an area of 663 acres. It is proposed to put in two more open drains with a total of 3150 meters to reclaim another area of 212 acres.

A tile drained project was visited at Manjri near Poona (Maharashtra). A main drain 15,000 feet long had been constructed using 9″ diameter pipe, and 13,000 feet of lateral tile drains of 6″ diameter had been placed.

These tile drains have been placed 5 to 7 feet deep with spacing between laterals of 660 feet except for drains No. 5 to 7 which are 330 feet apart. This drainage system has reclaimed 360 acres of land. The tile drains were working satisfactorily.

Himachal Nagwain Tile Drainage Project—This tile drainage project has been designed and executed with the advice and guidance of West German experts. The laterals are constructed out of tile bricks 9″ × 6″ × 3″ which have a semicircular 3″ diameter channel. Two bricks are put one over the other with channel faces together. It forms a continuous pipelike opening between them. The rows of bricks are lined on either side with gravel to form a filter. The laterals run up to 1000″ and empty into six inch diameter RCC hume pipe which are connected with a main drain made from 9″ RCC hume pipe. Laterals have been placed 40 feet apart and 3.25 feet deep. At the time of the visit the drains had been completed in 88.08 acres. The land has been reclaimed and is growing paddy then wheat during rabi, whereas prior to drainage it could support only the one crop which had to be paddy. Six more such projects have been completed at different places

(Jeral, Majethal, Cagal, Bhangrotu, Khandla and Bilaspur) and the total area drained is about 220 acres. The cost varied from Rs. 1,100 at Nagwain to Rs 500 at Cagal The cost will be further reduced when clay pipes are made with a tile press imported from West Germany.

Work has been executed on the basis of judgement and experience. No prior studies were made on the hydrology of the area or hydraulic conductivities of the soil to be drained. The project appears to be draining the area rapidly and successfully.

Mysore French-type drains having pieces of gravel were being tried at MALLIGARE Farm near Mandya in Mysore State. Trenches were of V shape three feet deep and eighteen inches wide. Gravels and vegetable debris was covered with earth. These were locally referred to as "jelly" drains. Spacing between the trenches was 250 feet. These drains were installed within a ten acre area and were said to be working satisfactorily.

4. Reclamation (leaching) Projects

Reclamation work is underway in the States of Punjab, Haryana and Uttar Pradesh.

In Uttar Pradesh a scheme of reclamation of saline and alkaline soils has been started. The work has been entrusted to N.E.S. Blocks of selected districts. Cultivators are being induced to take up work towards recalmation. Cost of irrigation for leaching and for raising paddy crop for first three years is being entirely subsidized. Reclamation work is also being done by the Agricultural Department of Uttar Pradesh.

Drainage work to lower water tables is in progress in the Punjab and Haryana under the direction of the Irrigation Departments of these States. Saline waterlogged areas are involved but as these areas do not occur in long stretches, there may be nonsaline waterlogged areas in between.

5. Research Work Underway in India

Design of open and tile drains—No research work seems to have

been carried out in India to find suitable depth, width, shape, capacity and spacing for open field drains. However, work has been undertaken recently at Punjab Agricultural Engineering College, Ludhiana, where both surface and sub-surface drainage systems are to be studied in order to evolve design criteria. Work on open drains to drain the waterlogged area of the farm and adjoining cultivators' fields was started in May, 1966. It was being completed at the time of visit of the Team in January, 1967. The projected work on tile drains is still to be started.

In the farm of the Botany Division of the Indian Agricultural Research Institute, Delhi, tile drains were laid out in 1962-63 under the guidance of Mr. J. D. Traywick, Agricultural Engineer of Rockefeller Foundation. These were installed to drain an area of 15 to 20 acres and are working effectively. Installation costs for the project were about Rs. 750 per acre.

In Delhi, porous concrete drains have been installed along the Central Vista to assist drainage of this area which would become waterlogged during the monsoon period. So far these drains have been working satisfactorily.

At the Ibban subsurface Drainage Research Station of the Irrigation Research Laboratory, Amritsar, a semifield investigation is being conducted. Drains consisting of "Collar Kalabas" (burnt clay tiles), straight Kolabas, porous concrete pipes, flat brick tiles and timber drains were installed at 6 foot depths. From results oft hese studies it has been concluded that flat brick tile drains function best followed by porous concrete pipe. The 'Kolabas' were weak and some collapsed in a year's time.

From the above it is evident that no definitive research work has been done on design, spacing, depth etc. of tile drains. Such tile drains as have been installed have been put dawn on the basis of best judgement to meet the need for drainage.

Drainage by tubewells—Tubewells as a means for lowering water tables were tried in the Punjab between 1911 to 1917 at three places.

These experiments were not successful because the tubewells were too few. Recently, better designed research work has been started to evaluate tubewell pumping as a means for lowering water tables.

Shallow tubewell pumping influences on the water table are being studied at the Irrigation Research Laboratory, Amritsar, at its 20-acre shallow tubewell Research Station near Amritsar. It has been observed that shallow tubewells cause greater lowering of the sub-soil water level than comparatively deep tubewells installed at 100 feet or more depth. It was stated that shallow tubewells sunk at 50 feet or so were effective in lowering the water table. Work is still in progress and the final evaluations will require further testing for longer period and on larger field scales.

Waterlogged Saline and Alkaline Soils—Experiments to determine the effect of amendments alone and amendments with fertilizers in reclaiming waterlogged saline and alkaline lands were studied in the *Punjab at Nilokheri.* The soil was both saline and alkaline with a pH of about 10.0. The water table was at about six feet during summer but at three feet during monsoon. Yields of paddy and barley could be increased by the application of gypsum along with nitrogenous and phosphatic fertilizers, but normal yields could not be obtained. The results of these trials demonstrated that drainage of these soils was essential as part of any reclamation procedure.

Experiments conducted at Government Usar Reclamation Farm, Chakeri, *Kanpur (Uttar Pradesh)* have shown that soils with impeded drainage could be reclaimed by breaking the hard pan by mechanical shattering and adding organic matter. In this area a clay pan about 36 inches below the surface was responsible for impeded drainage. The land was waterlogged during the monsoon. By mechanically breaking the hard pan, 400 acres of land were reclaimed. This method is being used effectively where waterlogging is due to impervious hard pan within 3 feet of the surface.

Reclamation of coastal saline soils—Saline and alkaline soils are found in the inland and coastal areas of the States of West Bengal, Orissa, Andhra, Madras Kerala, Maharashtra and Gujarat. It is

estimated that there are 20 to 30 thousand square miles of such land and that nearly half is reclaimable.

Pilot projects to reclaim such lands have been started in Maharashtra, Gujarat and West Bengal.

Various steps in the reclamation of these soils are:

(i) Protection of area from sea water, (ii) drainage of the area by means of a system of drain ditches, (iii) providing sufficient quantity of water for leaching of salts, (iv) application of amendments liks gypsum and farmyard manure.

Reclamation of these lands (locally known as Khar lands) is in progress at *Panvel Research Station* (*Maharashtra*). The work consists of a sea embankment 6 feet high and 2½′ above high tide level. Four drains 4′ deep spaced at 100, 200 and 400 meters have been provided to take out leaching water to a sump fitted with one way gate open to the sea but closed against tides. Fields between drains are divided into compartments by bunds spaced at 150′ intervals. Salts in these lands are leached down by storing rainwater (Rainfall 100 inches). When salts have been leached downward, 1 to 3 tons, of gypsum and 15 cart loads of farmyard manure are applied per acre.

A pilot scheme to reclaim such lands at *Vallabhpur* (*Gujarat*) has been started in consultation with Dutch engineers. It covers an area of 6,000 acres, of which 3,600 acres are to be reclaimed. Fresh water from the Vagad river is used to leach out salts. The land is divided into bunded plots surrounded by ditches placed parallel to one another at a distance of 650 feet. The ditches are six feet deep. Water from the river is put into the bunded plots and allowed to drain down and laterally to ditches connecting with a main channel which carries the leachates to the sea. This process will desalinize the soil in 2 to 5 years time. Work was delayed because sufficient leaching water from the river was not avaliable during the drought years. The results of this work are being watched closely with considerable hope for its success.

Work along similar lines as that started at Vallabhpur has been undertaken in *West Bengal* in the Sunder Bans area under the guidance of Netherlands engineers, to find out the effectiveness of the procedure for reclaiming the state's coastal saline lands.

Saline and alkaline areas with low water table—Large areas (Page 159) of such soils are present in Punjab (including Haryana), Uttar Pradesh and Rajasthan. This problem has been engaging the attention of the Government for over a century, but scientific studies were started in 1912.

In 1912 scientific studies of such soils were conducted in Uttar Pradesh. Later, other studies were begun at the Agricultural College and Research Institute, Lyallpur (Punjab) in 1916. Attention was placed on leaching salts. It was observed that salts later returned to the surface. Therefore, methods were tried like scraping or washing the salts away from surfaces. Trees and bushes that could remove the salts were planted. Acacia trees planted on an acre of a salt affected field at the farm of Agricultural Research Station, Lyallpur, lowered the salt content of the soil.

In 1918 it was found that about 30% of the area to be commanded by lower Bari Doab Canal in Punjab was unsuitable for cultivation due to the presence of considerable amounts of carbonates. The soils were hard and impervious, therefore, the usual method of leaching to remove salts would not work. Consequently, attempts to reclaim these soils were dropped in 1925. Further studies (1926-27) revealed that these soils contained a high amount of exchangeable sodium. Calcium chloride and gypsum, amendments made the soils permeable to leaching water, and the land was reclaimed sufficiently to grow wheat. These soils were low in nitrogen, and a good crop of wheat could be obtained only by applications of farmyard manure at rates of 15 tons per acre (1932).

Plots irrigated with canal water alone, also showed improvement. As these soils contained considerable amounts of calcium carbonate, calcium became available and replaced some of the

exchangeable sodium when plots were plowed and leached. Therefore, attempts were made to use calcium carbonate present in the soil by growing rice followed by berseem (1936) which was used as green manure. According to Dyer's citric acid method, these soils contained high amounts of available phosphorous but it was not available to a wheat crop. But, as exchangeable calcium gradually increased, the amount of phosphorous taken up by wheat plants also increased (1942). These results suggested that applications of phosphatic fertilisers could accelerate the process of reclamation. Experiments conducted at Kamma Khurd in Ludhiana Disrrict of Punjab confirmed these findings (1956-1959).

Press mud from sugarcane refineries in a waste product which contains 70% calcium carbonate, 0.4 to 0.5% N, 1.25% P_2O_5 and 8.9% organic matter (1956). This material was found suitable as an amendment in alkaline soil reclamation.

Dhaincha (Sesbania aculeata) proved better for green manuring than berseem. Dhaincha is grown before rice, and fertilized with 40 lbs. N and 40 lbs. P_2O_5. When it is 8 to 10 weeks old it is turned under. One to two weeks after green manuring, rice is transplanted. Fertilized with 40 lbs. rice makes use of phosphorous applied to the Dhaincha crop.

Molasses (10 to 15 tons. per acre), wastes and effluent from distilleries, and Argemone mexicana (2% N, 15% P_2O_5, 0.35% K_2O, and about 4.2% water soluble organic matter) have also been found to be useful in the reclamation of alkaline soils.

6. Institutions doing work on saline and alkaline soils

(a) Land Reclamation Irrigation and Power Research Institute. Amritsar (Punjab).

(b) Punjab Agricultural University, Hissar (Haryana).

(c) Indian Agricultural Research Institute, New Delhi.

(d) Government Agricultural College and Research Institute, Kanpur.

(e) The above are the main institutions where work on saline and alkaline soils is underway. Some work is also going on in the Agricultural Colleges of other States such as Madhya Pradesh, Andhra Pradesh, Rajasthan and Madras.

7 List of the publications consulted as an aid in assembling the above is given below. References (h) and (i) are private communications which form a large part of the body of this report.

(a) Study on waterlands including Saline, Alkaline and Water-logged lands and their reclamation measures. Committee on Natural Resources Planning Commission, New Delhi-1963.

(b) Review of Agricultural Research in the Punjab from 1947 to 1962. Vol. I Punjab Agricultural University, 1965.

(c) Reclamation of Saline and Alkaline Soils by Dr. H.L. Uppal. International Commission on Irrigation and Drainage. Sixth Congress (Question-19).

(d) Annual Progress Report (1958-59) of Reclamation of Alkaline and Saline Soils in the Punjab Government Agricultural College, Ludhiana. Scheme financed by I.C.A.R.

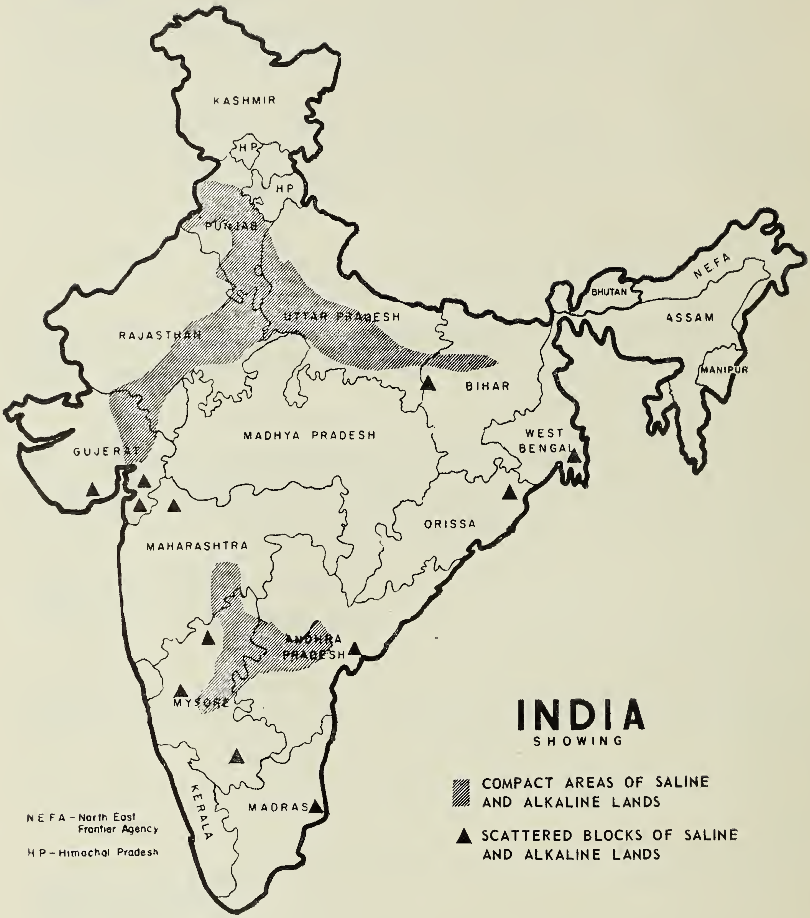
(e) Shallow Tube Well Research, Amritsar, by Dr. H.L. Uppal, Director, Land Reclamation, Irrigation and Power Research Institute, Punjab, Amritsar.

(f) Land Reclamation Volume III by Dr. C.L. Dhawan, Central Board of Irrigation and Power Publication No. 43.

(g) Indian Journal of Agricultural Science, 1932, 1936 and 1942.

(h) Research Activity in Soil and Water Management. Report No. PC-I. Prepared for visit of U.S. A.I.D. Team January 1967, Land Reclamation Irrigation and Power Research Institute, Amritsar.

(i) Notes received at the time of visits to Rajasthan, Punjab, Andhra Pradesh, Mysore and Maharashtra.


KASHMIR
H P
H P
PUNJAB
RAJASTHAN
UTTAR PRADESH
BIHAR
NEFA
BHUTAN
ASSAM
MANIPUR
GUJERAT
MADHYA PRADESH
WEST BENGAL
ORISSA
MAHARASHTRA
ANDHRA PRADESH
MYSORE
KERALA
MADRAS
INDIA
SHOWING
COMPACT AREAS OF SALINE AND ALKALINE LANDS
SCATTERED BLOCKS OF SALINE AND ALKALINE LANDS
N E F A – North East Frontier Agency
H P – Himachal Pradesh

APPENDIX 10

Proposed three Regional Centers for Research on the Application of the Principles of Drainage and the Management of Salinity and Alkalinity in Cultivated Soils of India

Proposed Location	Brief Description of Soils	Estimated acreage by States		
		Water-logged Saline High water-table	Saline-Alk. Low water-table	Water-logged
1. Maharashtra, Poona or Madhya Pradesh, Jabalpur	Black-soils	1,325,000	—	
	-do-	—	600,000	
2. Mysore, Bangalore	Mixed Red & Black Soils	550,000	450,000	
or Orissa, Cuttack	-do-	1,000,000	—	
3. Orissa, Cuttack Central Rice Res. Inst.	Coastal Alluvial Soils	1,000,000	—	
or West Bengal, Calcutta Eastern Regional Soil Correlator Center	-do-	2,100,000	—	

Professional Staff at each of three locations:

Class-I	*Class-II*	*Res. Assist.*
Soil Physicist	Asst. Soil Physicist	1 Soil Physicist
Drainage Engineer	Asst. Soil Chemist	2 S & W Engineers
	Asst. Plant Physiologist	1 Plant Physiologist
	Asst, Agronomist	1 Agronomist
		1 Soil Chemist
	Soil Classification-Correlation Officer	3 Soil Classifiers-Correlators
	Two Soil Classification-Correlators	2 Laboratory Assts.

Adequate support for nonprofessional staff, equipment, supplies, and facilities also should be provided (See page 58).

Summary and Recommendations from Report on Need of and Plan for

RESEARCH ON WATER USE and SOIL MANAGEMENT

towards meeting India's Food Shortages

by

Chester E. Evans, Perry R. Stout, Stephen J. Mech,
R. C. Hoon, S. D. Nijhawan, and C. S. Sridharan

International Agricultural Development Service

U. S. Department of Agriculture

Agency for International Development
U. S. Department of State

Indian Council of Agricultural Research
Government of India

The Government of India has stressed the need for developing a more intensive agriculture and through increased yields, meet the demand for greater food production. Proper use of India's soil and water resources is an essential element in this effort. Education, research, extension and implementation are all necessary to its success. This report deals with the research needed to support the overall effort. It summarizes the findings of a team of experts who conducted a study early in 1967 and developed recommendations for increasing the effectiveness of the present research program and listing the additional research projects required to provide needed technological information in soil and water management.

The USAID-INDIAN Water Use and Soil Management Research Consultant Team consisted of the following members:

Chester E. Evans, Team Leader and Branch Chief, Soil and Water Conservation Research Division, Agricultural Research Service, U.S. Department of Agriculture, Fort Collins, Colorado;

Perry R. Stout, Professor of Soil Science, University of California, Davis, California;

Stephen J. Mech, Research Irrigation Engineer, Soil and Water Conservation Research Division, Agricultural Research Service, U.S. Department of Agriculture, Prosser, Washington;

R.C. Hoon, Director, Central Water and Power Commission (retired), New Delhi;

S.D. Nijhawan, Agricultural Chemist (retired) Rohtak, Haryana;

C.S. Sridharan, Deputy Agricultural Commissioner (Engineering), Indian Council of Agricultural Research, Government of India, New Delhi.

SUMMARY AND RECOMMENDATIONS

At the request of ICAR-GOI, a team consisting of 3 U.S. Scientists supplied by USDA under AID sponsorship and 3 Indian Scientists assisted by several active organizations and groups, interviewed over 400 technical people; reviewed related problems, pertinent research activities, needs statements and publications, and facilities at 50 locations in 14 of India's States during the period of January 16 through April 28, 1967. The team, realizing the magnitude of the assignment, drew heavily on the experiences of many Indian colleagues in research and the excellent and comprehensive reports in the subject area which were prepared for our use.

A greatly accelerated level of research on water use and soil management problems in India in relation to food shortages is of the highest possible urgency. Water management research in India has been assessed and evaluated as India's neglected technology. The financial support at the central level for water use and soil management research is grossly inadequate. Research ways and means are charted for shifting management toward positive goals in solving production problems.

Recommendations are made for increasing effectiveness of research involving interdepartmental and interagency relationships. Soil and water conservation problems, research needs, and research program proposals are identified as to water sources, transportation and management of irrigation water to and on farm fields; waterlogging, salinity and alkalinity; soil, crop and climatic influences on irrigated, and rainfed agriculture. Recommendations for increasing

research effectiveness on immediate food production problems include considerations of:

1. Putting research of an applied or adaptive nature immediately at a level of high concern to the technical people if the goal of more food is to be achieved.

2. Rewarding scientists for efforts expended in adaptive research, and providing opportunity for professional advancement by means other than pyramiding through administrative channels.

3. Making salaries and related incentives for soil and water research scientists more competitive with those of scientists engaged in nonagricultural endeavors—industrial, construction, or other sectors of India's economy.

4. Arranging for more frequent and direct technical leadership and smooth coordination of research in various subject matter areas. These are urgently needed. To accomplish these objectives, the establishment of leaders of investigations, either on a national or regional basis, is recommended.

5. Improving exchange of technical information which must be achieved with least delay. The following three mechanisms to accomplish early information exchange are recommended:

a. Scheduling a series of technical workshops on water management.

b. Development by the ICAR of a systemized plan of routing and distributing interim reports, releases and publications to the soil and water research scientists in India on a timely basis.

Provisions for technical liaison with scientists in other

countries following the "scientist to-scientist" concept, for the purpose of exchanging current scientific information and publications.

6. Identifying Indian soil and water, scientists and institutions, which through technical competence and accomplishment in problem solving research have demonstrated capabilities of leadership in applied research programs. Additional resources and support should be channeled and concentrated toward scientific personnel and institutions so identified.

7. Identification in the next 2 years of qualified individuals in India, and arranging for expense-free opportunity for them to gain first-hand familiarity at foreign institutions of principles and practices in the irrigation-water use field.

8. Making contact through the ICAR with foreign universities, with the view of making arrangements to strengthen research and teaching in soil and water science at the graduate level in Indian institutions.

9. Consolidation of research projects and stations where possible in order to marshall the available scientific manpower toward the goal of increased food production and concurrently promote an interdisciplinary approach to the solution of agricultural problems.

Recommendations for improving interdepartmental and interagency relations and coordination should include clear policy declarations that:

1. In principle, the Ministry providing the leadership for the design and construction aspects of land and water development should also be responsible for the specialized research necessary to implement their programs. It is essential that these research activities be coordinated so that the efforts interlock, but do not overlap.

2. Within the Ministry of Food and Agriculture, water use and soil management research and training activities should be centralized as much as possible. It appears to the Research Consultant Team that this unit is logically the Indian Council of Agricultural Research (ICAR).

3. In the States, all agricultural and particularly all water use and soil management research and training activities except those at institutes, regional centers, and similar units directly and principally sponsored by the center and dealing with problems of regional and national significance in these fields, should be carried out by the agricultural universities within the States.

India's intensive crop production programs where adequate supplies of inputs such as seed of high yielding varieties, chemical fertilizers, plant protection materials, mechanization, credit, and trained manpower can be brought to bear show tremendous promise for success in rapidly alleviating food shortages. However, the missing technological links lagging far behind other essential inputs and the transportation and management of irrigation water to and on farm fields, general understanding of needs of specified crops, and good soil management practices. To provide essential technological information for the water and soil management component of the "Packages of Practices", the following research projects are recommended for initiation, implementation or strengthening as recommended in the full report whereby:

1. The best combinations of improved crop, soil, land shaping, fertilization, and tillage practices that might lead toward improved water use efficiency and higher yields of food crops, would be studied within eight river valley projects or tubewell command areas representing important geographic regions of India.

2. Adaptive type research programs on water use and soil management problems would be established at designated locations in six river valley projects.

3. There would be considerable strengthening of irrigation and water use research at 12 locations where essential land and laboratory facilities are available.

4. Pilot research projects would be initiated with high priority within selected command areas which will offer water for purchase on rate schedules based on volume delivery to encourage full water utilization and to discourage over irrigation.

5. A pilot research project would thoroughly study full case histories of water transmission and use from single outlet command areas. These would be reported upon in quantitative terms of real water use by cultivators of small holdings in relation to water actually delivered from the command area outlet.

6. A pilot research project would make complete studies of cultivators' organizational resources which could provide for equitable methods and rules for water distribution within the single outlet command area.

7. A research study on fundamental economies of lining canals, ditches, and cultivator's conveyance channels would be initiated in order to fully evaluate relative savings from minimizing (a) damage to land from seepage, (b) losses of water from seepage, (c) maintenance costs for weed removal, and (d) damages accruing from weed infestations. The cost and benefit estimates discovered from these studies should be compared with capital costs for lining conveyance channels when amortized over periods of 10, 15, 20, and 25 years.

8. A pilot research project would be initiated whereby lining materials for ditches for conveying water to cultivator's field can be tested and evaluated under practical field operating conditions within a variety of typical command areas.

Of equal importance to the research proposals listed above in

meeting India's future food needs are steps in research which will lead into longer term programs. Those recommended for early initiation are:

1. Establishment of coordinated drainage-salinity pilot research projects at one national center and three regional centers to evaluate the application of principles of drainage and the management of salinity and alkalinity in cultivated soils of India.

2. In States other than those selected for the centers and where salt problems are acute, appointment of an Indian scientist having a depth of knowledge as to methodology, equipment, and principles and practices for managing salt-affected soils, to be responsible to the interests of cultivators faced with salinity problems even though total areas involved may be relatively limited.

3. A research program on basic soil properties in relation to soil and water management practices and production of crops would be initiated at four centers in India.

4. Establishment of a central water management research center at the Indian Agricultural Research Institute (IARI) to study water management problems of national significance and to serve as a focal point for the training of people, and for coordination of other programs in India dealing with the management, conservation, and use of water for crop production both in irrigated and rainfed lands.

5. Because of the great importance of wells as a source of irrigation water, research would be directed toward problems of well design, construction and maintenance including materials and equipment and evaluation of pumping costs.

6. Based on an interdisciplinary and interagency committee's deliberations, an appropriate budget for research on tanks

as catchment and storage structures for water supplies would be established so that various soil groups and climatic belts in India can be advised of the most efficient means of effecting water conservation through construction and maintenance of tanks in small catchment areas.

7. A minimum of three research projects would be established to study problems of recharge of underground aquifers to be located at qualified institutions in principal irrigated regions.

8. The consultant team studied problems of rainfed lands only in very broad terms. But from evidence observed the team recommends the examination of existing approaches to research on rainfed lands and a substantial strengthening of programs at the soil conservation research, demonstration and training centers throughout India. Emphasis would be placed on small watershed hydrology, sedimentation, and the management of water its infiltration, storage and drainage from soils and safe disposal of excessive amounts from these rainfed lands having widely varying soil characteristics and slopes.

In connection with other essential activities, including the appointment of study groups or committees, it is suggested that:

1. USAID explore with ICAR its need for experienced foreign specialists to assist with such additional planning activities that may be desirable and needed

2. An Indian study group be formed with interdisciplinary and interagency representation to study the benefits which might accrue from research studies of tanks in relation to improvements which could contribute to India's economic development and to make recommendations for practical ways in which to get an effective research program started.

3. The ICAR actively consider possibilities for chemical

control of aquatic weeds within the realization, however, that India's water distribution systems pose special problems involving use of water for human and animal consumption.

4. A technical committee of Indian scientists be designated to make an assessment of existing findings for rainfed lands, publish the results, and make detailed suggestions as to the direction and orientation of needed soil and water conservation research expansion for rainfed lands in India.

5. If not already surveyed, existing experimental fields and those planned for research in India should be surveyed and characterized as to the kinds of soil represented by the test areas.

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